VAN NOSTRAND'S

ENGINEERING MAGAZINE.

NO. CCXV.—NOVEMBER, 1886.—VOL. XXXV.

NEW PRACTICAL FORMULAS FOR THE RESISTANCE OF SOLID AND BUILT BEAMS, GIRDERS, ETC., WITH NUMEROUS PROBLEMS AND DESIGNS.

By P. H. PHILBRICK, Professor of Civil Engineering, State University of Iowa.

Written for Van Nostrand's Engineering Magazine.

II.

We will now apply the preceding formulas to the different forms of beams, etc.

Eye Beams.

To find the moment of resistance about an axis mn, through the center of gravity of the section and parallel to ab. The

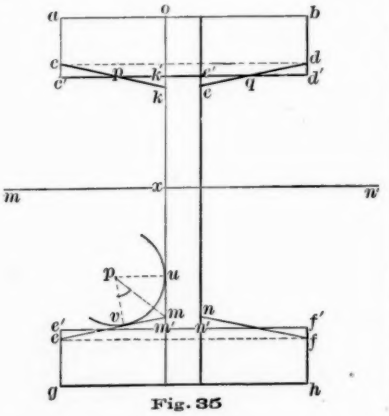


Fig. 35

flanges are usually trapezoidal. We will for the present consider the web as extending through the whole depth of the beam.

Let $abdlnfhgemkc$ represent the eye-beam. Through the middle points, p and q, of ck and ld, draw the line $c'k'l'd'$; also through the middle points of em and fn draw $e'm'n'f'$. Consider for the present $abd'l'n'fhge'm'k'c'$ in place of the original figure.

Let $h'=ac$, the least thickness of the flanges.

$H=ok$, the greatest thickness of the flanges.

$t=kl$, the thickness of the web.

$b=ab-kl=$width of flanges.

$h=\frac{H+h'}{2}=$ average thickness of the flanges.

Let $D=ag=$ total depth.

$d=ox=$ one half of total depth.

$D_1=c'e'=$ inside depth of new figure or average depth of original figure.

$d_1=k'x$, one half of the inside depth.

Let $a=$area of each flange$=b\,\frac{h'+H}{2}=bh$.

$B=$ area of web $=t.D$.

Now, by number 2 of table 1, the moment of resistance of the web on either side of the axis is $\frac{1}{3}\times\frac{1}{2}B\times\frac{1}{2}D=\frac{1}{12}BD$;

and by (55) the moment of resistance of either flange $= a\left(\frac{1}{2}D_1 + \frac{h^2}{\frac{2}{3}D_1}\right)$

Hence the total moment $= m = D_1 a + \frac{1}{6}DB + \frac{4ah^2}{3D}$ (73)

or since $a = b\frac{H+h'}{2}$ and $h = \frac{H+h'}{2}$

$$m = D_1 a + \tfrac{1}{6}DB + \frac{b}{6D}(H+h)^2 \quad (74)$$

But it is easy to show that the moment of resistance of the new figure exceeds that of the original figure by $\frac{bD_1}{6D}(H+h')^2$

Hence $m = D_1 a + \frac{1}{6}DB + \frac{b}{6D}[(H+h)^2 - D_1(H-h)^2]$. (75)

$= D_1 a + \frac{1}{6}BD$ very nearly. (76)

Eq. (76) applies at once to built beams, but the flanges are not the same as for solid beams and hence the value of D_1 for built beams remains to be pointed out.

With reference to (75), we remark that the quantities within the parentheses are necessarily small, their difference is therefore necessarily small and the factor $\frac{b}{6D}$ being but a small fraction, the product of this by the quantity within the brackets is, in practical cases, but a fraction of a unit—usually a very small fraction.

If in (76) we ignore the web we have,

$$m = D_1 a \text{ very nearly} \quad (77)$$

or $m = Da$ approximately. (78)

Let us now suppose the web to terminate inside the flanges, and let A = the area of a flange, and b = the area of the web.

Then we may write $m = AD_1 + \frac{1}{6}bD_1$

$= D_1(A + \frac{1}{6}b)$. (79)

The term AD_1 is slightly too small for the flange and $\frac{1}{6}bd_1$ too large for the web. On the whole the formula gives results very nearly correct, but slightly in excess.

If we ignore the web altogether, but use D instead of D_1 for the lever arm of A, we have $m = AD$. (80)

Equation (79) is the proper practical formula for solid beams in all cases, though (76) may be used when greater accuracy is desired, which can scarcely be the case, however. It is a significant fact that equation (80) which ignores the web, and requires but one multiplication, produces results *more* accurate than the *most* accurate formulas in general use. We will now set forth the usual formulas and then exhibit the merits and demerits of them all, in a general comparison.

If in (76) we substitute for both D and D_1, the distance g between the centers of gravity of the flanges, we get,

$$m = g(a + \tfrac{1}{6}B) \quad (81)$$

This is used by J. A. L. Waddell and others.

Writing g for D_1 in 79 we get

$$m = g(A + \tfrac{1}{6}b) \quad (82)$$

Writing g for the lever arm of the flange in (79) we find,

$$m = Ag + \tfrac{1}{6}bD_1 \quad (83)$$

This is the same as equation (5), Article 65, of Prof. Burr's "Elasticity and Resistance of the materials of Engineering." It is intended for use, and is extensively used. It is highly recommended by A. P. Boller, in his Highway Bridges, page 111.

If we consider the flanges for their whole depth, and the web as extending to the *middle* of the flanges and represent it by b', we may write,

$$m = g(A + \tfrac{1}{6}b'). \quad (84)$$

Omitting allowances for extra diagonal resistances, recognised by Mr. Daniel K. Clark and others, the above is Mr. Clark's formula for eye beams, etc.

To show how erroneous the common formulas are, we will give the true resistances of the 13 eye beams rolled by Carnegie, also the resistances by our equations (76), (79), (80). By the side of these, we will give the resistances by equations (81) and (82) and add an example to illustrate equations (83) and (84).

Omitting No. 13, which is not a practical beam, we observe that our equation (76) gives results almost exact; and that (79) is also practically accurate; while equations (81) and (82) give results in excess of about 5% and 10% respectively, and are therefore too erroneous to be countenanced in good practice. Besides, they involve far more labor than the far more accurate formulas recommended above. Thus are they doubly condemned

MOMENT OF RESISTANCE.

Number of Beam.	True Moment.	Moment by (76).	Moment by (79).	Moment by (80).	Moment by (81).	Moment by (82).
1	70.60	70 50	72 05	66.00	72.96	76.81
2	90.38	90.23	92.70	85.80	93.66	100.09
3	45.96	45 95	47.09	44.50	47.68	50.62
4	31.30	31.41	32 11	29.79	32.55	34.28
5	29.97	29.96	30.51	31.03	31.65	33.07
6	21.68	21.68	22.41	22 59	22.90	23.84
7	35 34	35.23	36.40	36.13	37.08	40.41
8	17.50	17.47	17 81	18.10	18.46	19.37
9	13.13	13.08	13.35	13.35	14 00	14 52
10	8.16	8 16	8.31	8.50	8.62	9.02
11	4.94	4.93	5.03	5.12	5 21	5.47
12	3.09	3.08	3.15	3.25	3 27	3.46
13	2.06	2.03	2.07	2.50	2.27	2.39

and the use of them therefore doubly absurd.

The following from Boller's Highway Bridges, page 111, will illustrate equations (83) and (84).

$$t=\tfrac{1}{2}, D_1=13, h=1, b=5, D=15$$
$$\therefore A=5, b=6.5 \text{ and } g=14$$

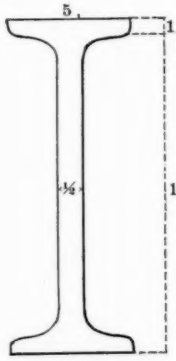


Fig. 36

Hence by (83)

$$m=14\times5+\frac{13\times6.5}{6}=70+14.083$$
$$=84.083$$

Now the true value of M is

$$\frac{5\times15^3-4.5\times13^3}{6\times15}=77.65$$

Hence the error $=6.43$

Now $6.43\div77.65=8.3\%$ nearly

By equation (84), we have

$A=5, b'=14\times\frac{1}{2}=7$ and $g=14$.

Hence, $m=14(5+\frac{7}{4})=86.33$

Therefore this is $86.33-77.65=8.68$ in error.

This is an error of $8.68\div77.65=11.2\%$ nearly.

The formula deduced by Mr. Clark is, $m=g(A+.28888b')$ or $m=14(5+2.0216)$
$=98.30$

The error in the former result shows, however, the total error of the result due to mathematical errors in the corresponding formula.

We observe that equation (80) does indeed give results more accurate than any of the common formulas in use. This shows that a direct though random shot may rest nearer the center than others obliquely though deliberately aimed. Since the errors of these common formulas far exceed the allowable limit, it follows that the errors involved in their use are not fully appreciated by those who use them.

For example, the author of a desirable treatise on "Designing of Ordinary Iron Highway Bridges" uses Eq. (83) and considers it safe; though, comparing it with equation (76), we see that the excess given by it for the flanges exceeds many times the deficiency given for the web.

The author from whom Eq. (83) and the example under it are quoted, remarks that; "the above process for obtaining the value of R [that is, the moment of resistance, which we have represented by m] varies so fractionally from absolute truth, that the refinement of calculation, necessary to obtain mathematical exactness, is entirely unnecessary."

Eq. (83) gives, however, only a rough approximation to the truth, while Eq. (76) shows that a *proper* equation with no "refinement of calculation" whatever, is all that is necessary to obtain a practically perfect result. Indeed (76) is of the same form as (83), though (76) does not, for reasons already given, involve g. It is believed that all the practical formulas, so called, heretofore used contain the standard errors on this subject.

So far, we have said nothing about the metal in the curved corners, which it is customary and proper to take no account of. We will, however, show how the moment of resistance of the corners may be easily obtained.

In Fig. (35), draw the radii uP and vP and join Pm. Let the angle mP$v=\theta$.

The area of $vmu\mathrm{P}=um\times u\mathrm{P}=(u\mathrm{P})^2 \tan\theta=r^2\tan\theta$.

The area of the sector $vu\mathrm{P}=\frac{1}{2}$ arc $vu \times u\mathrm{P}=(u\mathrm{P})^2\theta=r^2\theta$.

Therefore the area of the curved corner $=r^2(\tan\theta-\theta)$, and the area of the four corners $=4r^2(\tan\theta-\theta$.

Also $mx=\frac{1}{2}\mathrm{D}-\mathrm{H}$, and the strain at m is equal to $\frac{\frac{1}{2}\mathrm{D}-\mathrm{H}}{\frac{1}{2}\mathrm{D}}=\frac{\mathrm{D}-2\mathrm{H}}{\mathrm{D}}$.

Hence the moment of resistance of the four curved areas is, very nearly,

$$4r^2(\tan\theta-\theta)\frac{\mathrm{D}-2\mathrm{H}}{\mathrm{D}}(\tfrac{1}{2}\mathrm{D}-\mathrm{H})$$

$$=2r^2(\tan\theta-\theta)\frac{(\mathrm{D}-2\mathrm{H})^2}{\mathrm{D}}$$

This averages about 2% in Carnegie's beams Nos. 1 and 2 and less than 1% in the others.

The moment of resistance of eye beams about any axis is best found by finding the moment of resistance of the flanges and the web (or parts of the flanges or web, if the axis passes through flange or web) separately, and adding; or, if the moment m about mn is known we may use the formula of reduction (64).

Channel Bars.

The preceding formulas apply directly to channel bars, a or A being the area of a flange, or total area of flanges on one side of the axis, when two (or more) channels are used; B or b the area of a web or of the webs.

Since, however, the flanges of channels are thin, compared with the depths of the channels, those formulas give results for channels even more accurately than for beams.

Center of Gravity.

Since the neutral axis is assumed to pass through the center of gravity of the section, it becomes necessary to find, in some cases, the position of the center of gravity, or at least of the axis passing through it, in order to find the moments of resistance and of inertia.

The center of gravity of a body may be defined as the center of the forces of gravity, assumed to be parallel, acting upon the body.

If the center of gravity of a body is supported, the body will be supported, for the forces of gravity balance about the center of gravity.

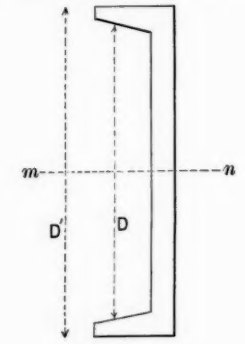


Fig. 37

For our purpose, it will be necessary to consider, to a limited extent only, the center of gravity of areas. The center of gravity of any regular polygon is at the center of the inscribed or circumscribed circle of a parallelogram at the intersection of the diagonals; of a plane triangle on the line joining the vertex with the middle of the base and at one-third the length of this line from the base; of a circle or ellipse, at the geometrical center of the figure, etc.

We observe that the center of gravity of any section symmetrical with reference to an axis, will be found on that axis; so that for such sections it is only necessary to find one line upon which the center of gravity is situated, the center of gravity being at the intersection of this line with the *symmetrical* axis.

To find the center of gravity of a double "T" eye beam with unequal flanges.

Let a' be the area of the upper flange, a'' that of the lower flange and b that of the web, as shown in Fig. 38, d', d'' and d, the distances of their centers of gravity from the *base* of the beam, and x the same for the whole figure.

Let A = the total area. Then taking moments about the base we have:

$$(a'+a''+b)x=bd+a'd'+a''d''$$

$$\text{or } x=\frac{bd+a'd'+a''d''}{a'+a''+b} \quad (85)$$

The center of gravity is, of course, on the center line of the web.

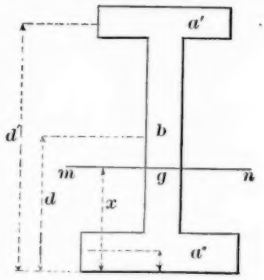


Fig. 38

Or, let the lever arms be measured from the center of gravity of the lower flange as indicated in Fig. 39.

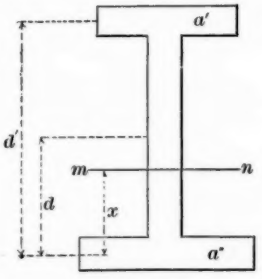


Fig. 39

In this case $d''=0$, and we have:

$$x=\frac{bd+a'd'}{a'+a''+b} \qquad (86)$$

If h = the thickness of the lower flange, the distance from the base of the beam to its center of gravity is,

$$x=\tfrac{1}{2}h+\frac{bd+a'd'}{a'+a''+b} \qquad (87)$$

These equations apply equally to the case in which the web is neglected, by putting $b=0$ in them.

Considering the web extending the whole depth of the beam, as in Fig. 40, we may easily find the distance of the center of gravity from the center of the beam.

The areas being represented as before, let g be the center of gravity of the web, and g' that of the beam. Let $gg'=x$ and let d' and d'' be the distances from the centers of the flanges to the center of the web.

Taking moments about g, we have:

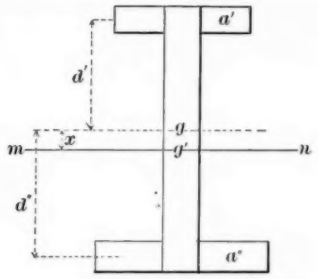


Fig. 40

$$(a'+a''+b)x=a''d''-a'd'$$

$$\text{or } x=\frac{a''d''-a'd'}{a'+a''+b} \qquad (88)$$

The above formulas apply without change to Deck Beams.

Let Fig. 41 represent a single "T."

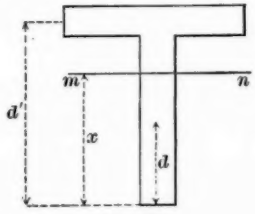


Fig. 41

Take moments about the end of the stem and find the distance from the end of the stem to the center of gravity of the section, $x=\frac{bd+a'd'}{a'+b}$. (89)

If d and d' are measured from the outside of the flange, eq. (89) will also give x, *measured from the same line.*

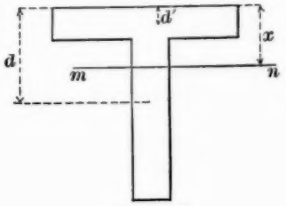


Fig. 42

Supposing the coefficients of elasticity for tension and compression to be equal, in which case the neutral axis does pass through the center of gravity of the sec-

tion, it is evident that the greatest strain would be on the end of the stem, and that the value of x, found from Fig. 41, would be the proper value to be used.

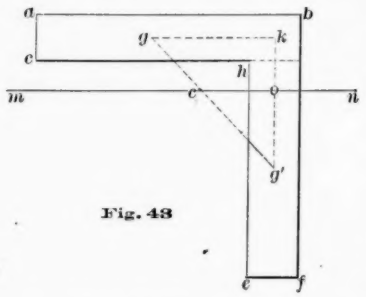


Fig. 43

It is evident that (89) applies without change to finding the position of the axis mn, through the center of gravity of angle irons, parallel to a leg, whether for equal or unequal legs. The position of this axis is all that is required in practice.

If, for any reason, the *center* of gravity is required, it may be easily found as follows:

Find mn as above; then observing that the centers of gravity, g and g', of the legs are at their geometrical centers, join g and g'. The intersection c with mn determines c, the center of gravity.

Or, let a= area of upper leg, and a' that of the lower. Take c such that

$$\frac{cg}{cg'}=\frac{a'}{a} \text{ or } \frac{cg}{gg'}=\frac{a'}{a+a'} \text{ or } cg=\frac{a'}{a+a'}\times gg' \qquad (90)$$

This determines the position of c. Drawing gk and $g'k$ parallel to ab and bf we have:

$$\frac{Ok}{kg'}=\frac{cg}{gg'}=\frac{a'}{a+a'} \text{ or } Ok=\frac{a'}{a+a'}\,kg' \qquad (91)$$

This determines the position of the axis mn, with reference to k and g' and therefore with reference to ab and ef.

For an obtuse angle iron, it is evident that the line gg' will be divided at c and therefore the line kg' at o in the same ratio as though the angle was right; and since the line kg' is of the same length as for a right angled "angle," ko is also the same. This gives an easy way of finding the position of mn.

The perpendicular distance of mn from ab and ef, are equal respectively to or sin. gkp and op sin gkp.

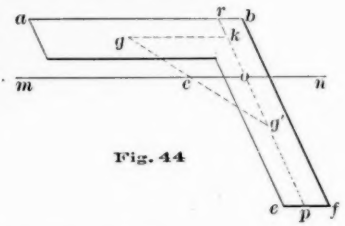


Fig. 44

To find the axis through the center of gravity of a channel parrallel to the web, consider each flange divided into a rectangle and a triangle as shown:

Let t=thickness of the web,
h=height of a flange,
x=distance from back of channels to the center of gravity of the channel,
b=area of the web,
a=area of the rectangular portion of a flange,
a'=area of the triangular portion of a flange,
and A=the total area of the channel.

Fig. 45

Taking moments about the back of the channel we have,

$$(2a+2a'+b)x=b\times\tfrac{1}{2}t+2a(t+\tfrac{1}{2}h)+2a'(t+\tfrac{1}{3}h),$$

$$\text{or } x=\frac{t(2a+2a'+\frac{1}{2}b)+h(a+\frac{2}{3}a')}{2a+2a'+b} \qquad (92)$$

In a similar manner we easily find the center of gravity of all practicable forms.

Deck Beams.

To find the moment of resistance about any axis.

If the beam is of the form shown in Fig. 46 which is the common one, eq. (65), will give the moment of the two

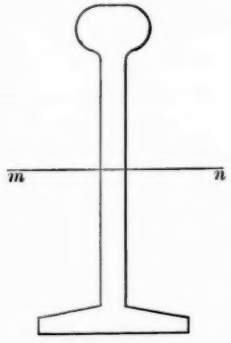


Fig. 46

semicircles or circle; the formula for number 2 of Table I. the same of each part of the web above and below the axis; and eq. (55) of the flange.

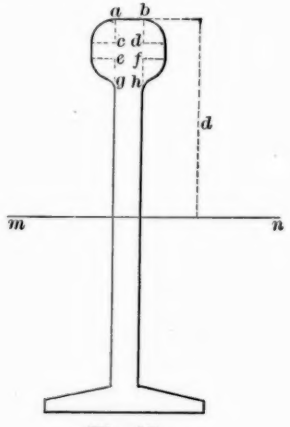


Fig. 47

If the beam is of the form shown in Fig. 47 eq. (68) or (69) will apply to the upper semicircle and eq. (70) or (71) to the lower, etc. It is easy to see, however, that the lever arm of the head as a whole, is in value between that of a circle whose diameter is $ag=h$ (say), and that of a rectangle of the same height. Either one of these lever arms may be used in this case with very great accuracy indeed.

Star Iron.

To find the moment of resistance about the axis AB. Prolong the edges *ec*, *fd*, etc., to the axis as shown, Fig. 48.

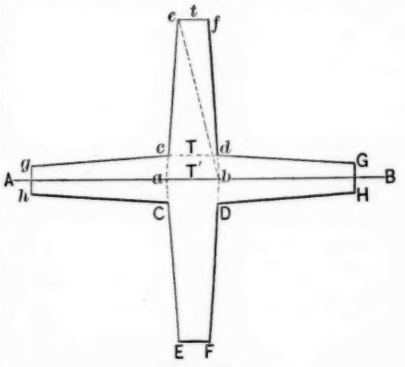


Fig. 48

Let $ef=t$, $cd=T$ and $ab=T'$, $eE=D$.

For the moment of resistance of the vertical stems, consider each divided into triangles by diagonals *be*, etc. Then from the formulas for numbers 3 and 4 of Table I.

$$M_1=2\left\{\tfrac{1}{12}T'\left(\frac{D}{2}\right)+\tfrac{1}{4}t'\left(\frac{D}{2}\right)^2\right\}=\tfrac{1}{24}D^2(3t+T') \quad (93)$$

Since the moment of the horizontal stem is very small compared with the vertical stem, we may consider the former to be flat, as was done in treating the flanges of the eye beams in Fig. 35. We thus find the moment of resistance of the horizontal stem to be

$$M_2=\tfrac{1}{48}\frac{D-T}{D}(t+T)^2 \quad (94)$$

(93) and (94) give for the total moment

$$M=\tfrac{1}{24}D^2(3t+T')+\tfrac{1}{48}\frac{D-T}{D}(t+T)^2 \quad (95)$$

or $M=\tfrac{1}{24}D^2(3t+T')+\tfrac{1}{48}(t+T)^2$, nearly. (96)

These represent to the best advantage the usual formulas for this case. We

will, however, derive a formula twice as short and three times as accurate.

We notice that the area cut off, in rounding the four corners at e, f, E and F is a little less than the difference between the areas of a square and a circle, whose diameters are each equal to t.

This difference is $=t^2-\frac{\pi}{4}t^2=.2146t^2$.

The lever arm of this area is a little less than $\frac{D}{2}$. Hence the moment is a little little less than

$$.2146t^2\frac{D}{2}=.1073t^2D \text{ or } M'=\tfrac{1}{10}t^2D,$$

very nearly. (97)

The total moment is, therefore,

$$M=\tfrac{1}{24}D^3(3t+T')-\tfrac{1}{10}Dt^2+\tfrac{1}{48}\frac{D-T}{D}(t+T)^3 \quad (98)$$

In regard to eq. (98), we observe that the term $\frac{1}{10}Dt^2$ is usually and properly disregarded; and that the term $\frac{1}{48}\frac{D-T}{D}(t+T)^3$, as well as the quantity $\frac{1}{24}D^3(T'-T)$ is in practical cases much smaller, and both together smaller than $\frac{1}{10}Dt^2$. Hence

$$\tfrac{1}{10}Dt^2-\tfrac{1}{24}D^3(T'-T)-\tfrac{1}{48}\frac{D-T}{D}(t+T)^3=0, \text{ very nearly.}$$

Adding this to (98), we obtain the moment of resistance

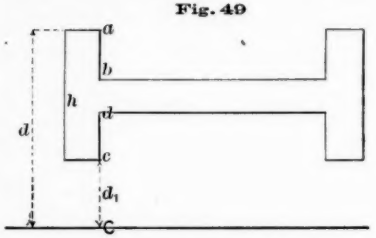
$$=M=\tfrac{1}{24}D^3(3t+T) \quad (99)$$

This is believed to be the simplest and most accurate approximate formula possible to deduce. The following table will show that, taking all the forms in Carnegie's book as a test, eq. (99) is three times as accurate as (96), or as the ostensibly accurate results (and they are sufficiently accurate) given in Carnegie's "Pocket Companion:"

Size.	Thickness in inches at the end and root of flange.	Eq. (96) or Carnegie's.	True moment eq. (98).	Eq. (99).
4 ×4	$\frac{9}{16}$	1.16	1.11	1.13
3½ × 3½	$\frac{1}{2}$	0.85	0.80	0.83
3 ×3	$\frac{7}{16}$	0.55	0 52	0.53
2½ × 2½	$\frac{5}{16}$	0 36	0.34	0.35
2 ×2	$\frac{1}{4}$	0.20	0.19	0.19
1½ × 1½	$\frac{9}{16}$	0.087	0.082	0.082

To find the moment of resistance of an eye beam, the neutral axis being any line parallel to the center line of the web.

Fig. 49



Let $ac=h$, $bd=t$, $Cd=d_2$.

The lever arm of the flanges is by eq. (55)

$$l_1=d+\tfrac{1}{3}\frac{h^2}{d}=d_1+.33\frac{h^2}{d} \quad (55)$$

To find the lever arm of the web. Supposing the strain at b equal to unity, the same equation would give the lever arm $=d_2+\frac{1}{3}\frac{t^2}{(d_2+t)}$. But the strain at b is $\frac{bC}{aC}=\frac{d}{d_2+t}$, and hence the lever arm $=l'$

$$=\left(d_2+\frac{t^2}{3(d_2+t)}\right)\frac{t^2}{d_2+t}=\frac{d_2^2+d_2t}{d}+\frac{t^2}{3d}=$$

$$\frac{(d_2+\tfrac{1}{2}t)^2}{d}+\frac{t^2}{12d}=\frac{(d-\frac{1}{2}h)^2}{d}+\frac{t^2}{12d}=d-h$$

$$+\frac{h^2}{4d}+\frac{t^2}{12d}=d_1+\frac{h^2}{4d}+\frac{t^2}{12d}=d_1+\frac{h^2}{4d'}$$

very nearly, (55′)

We observe that $\frac{t^2}{12d}$ will not amount, in average cases, to nearly one hundredth part of $\frac{h^2}{4d'}$ or to scarcely a perceptible part of the lever arm.

When $t=h$ (55′) gives $l'=d+\frac{h^2}{4d}+\frac{h^2}{12d}$ $=d_1+\frac{h^2}{3d}=l$ as it ought. An arithmetical mean of the above lever arms used for both stem and flanges will give results sufficiently accurate in almost all cases.

This lever arm is, $l=d+\frac{1}{2}\left(\frac{h^2}{3d}+\frac{h^2}{4d}\right)=d_1$

$$+\frac{7h^2}{24d}=d_1+.29\frac{h^2}{d}(55'')=d_1+.3\frac{h^2}{d}$$

nearly, (55‴)

If a=area of each flange and b that

of the web, we have from (55) and (55′), for the beam,

$$M_1 = 2a\left(d_1 + \frac{h^2}{3d}\right) + b\left(d_1 + \frac{h^2}{4a} + \frac{t^2}{12d}\right)$$

$$= 2a\left(d_1 + \frac{h^2}{3d}\right) + b\left(d_1 + \frac{h^2}{4a}\right) \text{ very nearly (100)}$$

or from (55‴), $M_1 = (2a+b)\left(d_1 + .3\frac{h^2}{d}\right)$ (101)

Channel Bars.

Let $ac=h$, $bc=t$ and an (n is at the middle of bc)$=h_1$, etc. The lever arm of the flanges, as we have just seen is $l=d_1 + \frac{h^2}{3d}$ Observing that, in reference to the web, $\frac{1}{2}h$ in Fig. 49, is the same as h_1

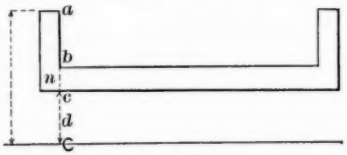


Fig. 50

in Fig. 50, eq. (55) gives for the lever arm of the web

$$l' = \frac{(d-h)^2}{d} + \frac{t^2}{12d} = \frac{(d-h)^2}{d} \text{ very nearly (102)}$$

The notation being as before, the moment is therefore

$$= M_1 = 2a\left(d_1 + \frac{h^2}{3d}\right) + b\frac{(d-h)^2}{d} \quad (103)$$

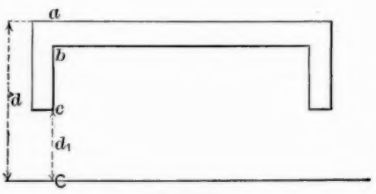


Fig. 51

In Fig. 51 let $ac=h$, $bc=t$, etc. Eq. (55) gives the lever arm of the flanges,

$$= l = d + \frac{h^2}{3d};$$

and the lever arm of the web

$$= l'' = d - t + \frac{t^2}{3d} = d - t, \text{ very nearly.}$$

Hence $M_1 = 2a\left(d_1 + \frac{h^2}{3d}\right) + b\left(d - t + \frac{t^2}{3d}\right)$

$$= 2a\left(d_1 + \frac{h^2}{3d}\right) + b\,(d-t) \text{ very nearly (104)}$$

These formulas evidently apply without change to angle irons, as shown in Fig. 52.

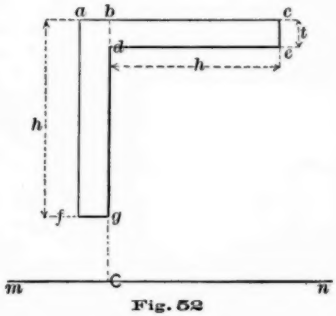


Fig. 52

We shall now apply the preceding formulas to finding the moment of resistance of compound beams, girders, etc., selecting our examples for the purpose from actual practice. We shall deduce formulas exceedingly short and practically perfectly accurate. We will first consider angle irons.

Referring to Fig. 52 the lever arm of the vertical leg is equal to $d - h + \frac{h^2}{3d}$, and of the horizontal leg to $d - t + \frac{t^2}{3d} = d - t$ very nearly.

Hence, supposing $bc=af=h$, we have the lever arm of the angle equal to an arithmetical mean between the lever arms of the legs$=l=\frac{1}{2}\left(d - t + d - h + \frac{h^2+t^2}{3d}\right)$

$$= d - \tfrac{1}{2}(h+t) + \frac{h^2+t^2}{6d} (105); \; = d - \tfrac{1}{2}(h+t)$$

nearly, which shows that the extremity of the lever arm, or the center of moments, is in this case nearly at (though a little above) the middle of dg.

Suppose, now, the horizontal leg to be shortened an amount $hc=ab=t$, so that $ah=af=h$, the legs being equal; to find the decrease in the lever arm of the angle. M, the middle point of dg, is the center of moments, very nearly, for the

angle acf; and o the same for the angle ahf. Let $mo=x$.

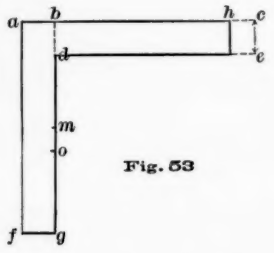


Fig. 53

Taking moments about m, and observing that the areas of the parts of the angle are as their lengths, we have:

$mo(af+bh)=do\times hc$, or $x(2h-t)=\frac{1}{2}(h-t)t$

$$\therefore x=\frac{t(h-t)}{4h-2t}<\frac{t(h-t)}{4h-4t}=\tfrac{1}{4}t, \quad \text{or} \quad x=\tfrac{1}{4}t$$

nearly. Subtracting this from (105), we have for equal legs—

$$\text{Lever arm}=l'=d-\tfrac{1}{2}(h+t)-\left(\frac{t}{4}-\frac{h^2+t^2}{6d}\right) \quad (105')$$

or effective depth

$$=D'=D-(h+t)-\left(\frac{t}{2}-\frac{h^2+t^2}{3d}\right) \quad (106)$$

Now, suppose the vertical leg$=h$ and the horizontal leg$=h+e$, then as above we readily find,

$$x=\frac{e(h-t)}{4h+2e}<\frac{eh}{4h+2e}<\frac{eh}{4h}=\tfrac{1}{4}e.$$

Applying this to all the forms rolled by Carnegie, taking average thickness of legs, we find the average to be

$$x=.172e=\tfrac{1}{6}e \text{ very nearly.}$$

Hence for unequal legs the lever arm is,

$$l''=d-\tfrac{1}{2}(h+t)-\left(\frac{t}{4}-\frac{h^2+t^2}{6d}\right)+\tfrac{1}{6}e \quad (105'')$$

And the effective depth is

$$D''=D-(h+t)-\left(\frac{t}{2}-\frac{h^2+t^2}{3d}\right)+\tfrac{1}{3}e \quad (107)$$

$\frac{t^2}{3d}$ is too small to take note of.

Again, $\frac{h^2+t^2}{l}$, is only a small part of unity, and furthermore, in no properly proportioned beam can this expression differ from $\frac{t}{2}$ by an appreciable amount—by an amount scarcely affecting the decimal places of the result. This becomes apparent when we reflect that, approximately, $t\propto h\propto D$, and hence

$$\frac{h^2+t^2}{3d} \text{ or } \frac{h^2}{3d}\propto\frac{d^2}{d}\propto d\propto D, \text{ and } \frac{t}{2}\propto\frac{h^2+t^2}{3d}.$$

For an average case, let $t=\frac{3}{8}$, $h=3$, $D=30$, we have

$$\frac{t}{2}-\frac{h^2}{3d}=\tfrac{3}{16}-\tfrac{1}{80}=\tfrac{1}{80}=.012.$$

The equations become, therefore, for equal legs,

$$D=D-(h+t), \quad (108)$$

And for unequal legs,

$$D''=D-(h+t)+\tfrac{1}{3}e. \quad (109)$$

In case of unlike angles for the upper and lower flanges we have the effective depth

$$=D''=D-\tfrac{1}{2}(h+h'+t+t')+\tfrac{1}{6}(e+e') \quad (110)$$

in which the accented letters refer to the angles on one of the flanges.

If $t=t'$, effective depth

$$=D''=D-\tfrac{1}{2}(h+h'+2t)+\tfrac{1}{6}(e+e') \quad (111)$$

Plate Girders.

Let Fig. 54 represent a single plate girder formed by a plate and four angles.

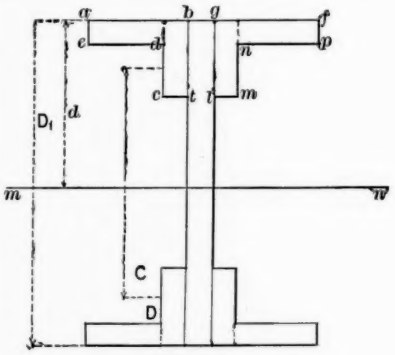


Fig. 54

In proportioning built beams, it is understood to be the duty of the web to maintain a rigid connection between the flanges; and it is usual to assume that "the flanges sustain all the horizontal strains and no other, and that the web sustains only the vertical strains."

Some engineers treat the web, as also resisting horizontal strains, the same as a beam with no flanges; and since it can

only partially do so, they attempt to correct the assumption by allowing a proportionately smaller strain per □″ of cross section. But this is plainly unphilosophical, since the ratio of the area of the web to that of the flanges is not constant. If anything at all is allowed for the web in resisting horizontal strains, such a part only of its resisting power as a beam, should be allowed as experiment will justify.

The flanges are frequently made equal, the supposition being, however, that the resisting power of the cross section of the compression flange in such cases, is somewhat greater than that of the net area (rivet holes deducted) of the tension flange.

I will in the following examples, give the results by my formulas, as well as those by the usual formulas, noting the errors of the latter.

Example 1. Web $20'' \times \frac{1}{4}''$; 4 angles $2\frac{1}{4}'' \times 2\frac{1}{4}'' \times \frac{1}{4}''$, as shown in Fig. 54. Instead of multiplying the area of each flange by its lever arm, we may multiply the area of one flange by twice its lever arm, or the "effective depth" of the beam.

Now, by (108), the effective depth $= D_1 = 2d - (h + t) = 20 - 2\frac{1}{2} = 17.5$. And the area of the two angles is equal to $a = 2\frac{1}{8}$.

Hence the moment by 77 is equal to $D_1 a = 17.5 \times 2.12 = 37.10$.

The true moment found by equation (106) is 37.28.

Taking the effective depth equal to the clear depth between the horizontal legs of the angles, which is the least value used in general practice, and, therefore, leads to the *least* error, we find the moment $= 19.5 \times 2\frac{1}{8} = 41.44$, showing an error of 4.08, or about 11%.

Example 2. Web $27'' \times \frac{1}{4}''$; 4 angles $3'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$.

The effective depth by (109)
$= D - (h + t) + \frac{1}{3}e = 27 - 2\frac{3}{4} + \frac{1}{6} = 24.42$.

The area of two angles $= 2.62$; and $24.42 \times 2.62 = 63.98$.

The true moment is 64.14.

Example 3. The floor beams of a bridge are $17\frac{3}{8}$ feet apart and $17\frac{1}{2}$ feet long from center to center of pins; and fully stiffened so that their length need not be regarded when considering the strains upon them. Roadway, 16 feet wide in the clear. Rolling load, 80lb per □ foot, or 1280lb per lineal foot of bridge.

A beam, web $20'' \times \frac{1}{4}''$ and 4, $3'' \times 2''$, 4lb angles ($\frac{1}{4}$ inch thick, area 1.19 □″) is proposed. Iron supposed to resist 8,000 pounds per square inch in compression and 10,000 in tension. Is the beam sufficiently strong?

1° The dead load per lineal foot of bridge is:

	Pounds.
Flooring (oak), $2\frac{1}{2} \times 16 = 40$ ft.; $40 \times 4\frac{1}{2} = 180$	
11 joists (pine), $\frac{3 \times 12 \times 11}{12} = 33$ ft.; $33 \times 3\frac{1}{3} = 110$	
2 felloe guards, $\frac{4 \times 6 \times 2}{12} = 4$ ft.; $4 \times 3\frac{1}{3} =$	13
Total,	303
Rolling load, $16 \times 80 = 1280$ pounds.	
Total per lineal foot,	1583 "

$1583 \times 17\frac{3}{8} = 27263$ = the external load on the beam.

Area of web $= 20 \times \frac{1}{4} = 5$ □″

and weight $= \frac{5 \times 10}{3} = 16.67$

Weight of angles per foot $= 4 \times 4 = 16.00$

Total, 32.67

Add for stiffening angles, filling plates and rivets, 20% = 6.53

39.20

Hence weight of beam $= 39.2 \times 17\frac{1}{2} =$ 673

Add, 27263

Total load $= 27936$

The moment of the load
$= m = \frac{27936 \times 17\frac{1}{2} \times 12}{8} = 719352.$

The compressive side of the beam is the weaker.

The effective depth of angles is by (109), $D_1 = 20 - 2\frac{1}{4} + \frac{1}{3} = 18\frac{1}{12}$, hence, *considering the web fully effective*, equation (76) gives for the moment of resistance of the beam;

$m' = 8000(18\frac{1}{12} \times 2.38 + \frac{1}{6} \times 5 \times 20) = 477630$

Now $\frac{4}{7}\frac{7}{1}\frac{6}{2}\frac{3}{3}\frac{9}{2} = 66$ nearly; and we find that the beam has at most, *according to the specifications*, about two-thirds of the required strength or capacity.

2° Disregarding the coefficient 8,000, and considering the tensile side to be the weaker. Using $\frac{5}{8}''$ rivets in $1\frac{1}{16}''$ holes, the angles being $\frac{1}{4}''$ thick, the area lost

by a rivet in each angle is $2\times\frac{11}{16}\times\frac{1}{4}$ $=.344''$.

Hence the effective area of a flange is $2.375-.344=2.03''$, and we have moment of resistance of beam

$=10000(2.03\times18\frac{1}{2}+\frac{5}{6}\times20)=533792.$

The beam has, under *this* supposition, a capacity of $\frac{533792}{715200}=74\%$ of that required.

3° Computing, according to the Carnegie formula, coefficients and all, which formula was professedly (though in view of the 8000 coefficient, inconsistently) used in this case; we have the moment of resistance of beam equal to

$$10000\times2.38\times20=476000.$$

Now, $\frac{476000}{715200}=.66$, showing that the beam has over 66%, or about $\frac{2}{3}$ of required capacity.

4° Referring to the Carnegie table we find the area required for each flange $=3.58$ square inches, and as we have an area equal to 2.38 square inches, the capacity of beam is $\frac{2.38}{3.58}=.66$, or 66% as above. We will try a web plate $\frac{1}{4}''\times24''$.

Flanges, four, $3''\times2''\times\frac{5}{16}''$ (5lb angles).

Weight of web $=\frac{\frac{1}{4}\times24\times10}{3}$		20
Weight of angles	$4\times5=$	20
		40
Add 20%		8
		48

Hence weight of beam $=48\times17\frac{1}{6}=824$

Add 27263

Total load 28087

The moment of the load

$$=m=\frac{28087\times17\frac{1}{6}\times12}{8}=723240.$$

The effective depth of flanges

$$=24-(2+\tfrac{5}{16})+\tfrac{1}{3}=22.02.$$

Hence $m'=8000(aD_1+\frac{1}{6}BD)$

$=8000(2.98\times22.02+24=717040.$

The beam is therefore about one-half of one per cent. only short of the capacity required, and is therefore satisfactory.

According to Carnegie we have moment of resistance $=10000\times2.98\times24$ $=715200$, showing a deficiency of about 1%.

A plate girder with flange plates. The effective depth of the flange plates is but little greater than the web plate D.

To find the effective depth of the angles we observe that were the strain at c unity, the effective depth by (109) would be $D-(h+t)+\frac{1}{3}e$. But the strain at c is equal to

$$\frac{mc}{ma}=\frac{d}{d+t_1}=\frac{D}{D+2t_1}=\frac{D-2t_1}{D}\text{ nearly.}$$

$$=1-\frac{2t_1}{D}\text{ nearly.}$$

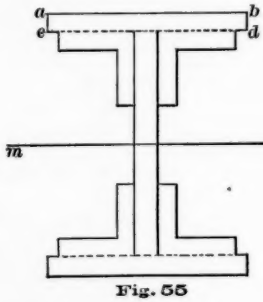


Fig. 55

Hence the effective depth is equal to

$$D''=[D-(h+t)+\tfrac{1}{3}e]\left(1-\frac{2t_1}{D}\right)=D-(h+t)$$

$$+\tfrac{1}{3}e-2t_1+$$

$$=D-(h+t+2t_1)+\tfrac{1}{3}e\text{ nearly.}\quad(109')$$

For equal legs, $e=o$, and we have effective depth

$$=D'=D-(h+t)-2t_1=D-(h+t+2t_1)\ (108')$$

Eqs. (108′) and (109′), compared with (108) and (109), show that the reduced effective depth of a section covered by a plate is approximately equal to the effective depth without the plate, less the thickness of the plate. Of course the principle applies to all sections situated substantially the same.

For unequal legs, with plates whose thickness is t_1, eqs. (110) and (111) become,

$$D''=D-\tfrac{1}{2}(h+h'+t+t')+\tfrac{1}{6}(e+e')-2t_1\quad(110')$$

and $D''=D-\frac{1}{2}(h+h'+2t)+\frac{1}{6}(e+e')-2t_1$ (111′)

For one plate we write in those several equations, t_1, for $2t_1$. The effective depth is to be used with the weaker flange.

Example—A track stringer (17 feet and one inch long from center to center of floor beam).

Web, $21\frac{1}{2}''\times\frac{5}{16}''\times16'.11\frac{1}{2}''$ long.

Upper flange. 2 angles $3\frac{1}{2}''\times3''\times\frac{5}{8}''$, one plate, $8''\times\frac{3}{8}''$.

Lower flange, 2 angles, $5''\times4''\times\frac{3}{8}''$.

(111′) gives, effective depth

$=21.5-\frac{1}{2}(3+4+\frac{3}{4})+\frac{1}{6}\times\frac{3}{2}-\frac{5}{8}=17.5.$

The lower flange is the weaker.

Area of lower flange is 6.47 □″.

Hence the moment is $6.47\times17.5=113.22$.

Were the depth of the web taken for the effective depth, the error would be, $\frac{21.5-17.5}{17.5}=23\%$ nearly.

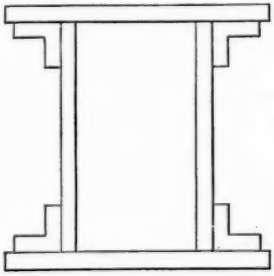


Fig. 56

A box girder (Fig. 56) may be treated precisely as a plate girder, the former having two web plates, the latter one.

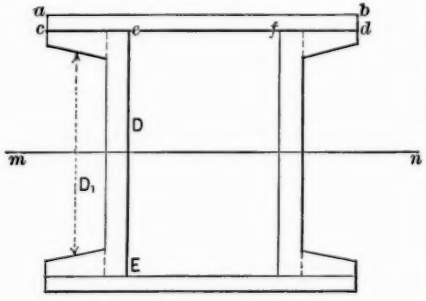


Fig. 57

A, box girder as shown in Fig. 57.
D being the depth of channels;
D_1 average depth between flanges;
b the area of the webs;
a the area of flanges on one side of the axis;
t average thickness of flange;
A the area; and
t_1 the thickness of a plate.

Eq. (55) gives the effective depth of plates but little greater than D; and the same eq. observing the remark under eqs. (108′) and (109′) shows the effective depth of the web to be but little greater than $D-2t$, and that of the flanges a little greater than $D_1-2t_1=D-2t-2t_1$.

The effective depth for the channels and plates together will not vary much from $D-2t_1$.

Hence the moment

$$M=(a+A+\tfrac{1}{6}b)\,(D-2t_1) \quad (112)$$

Example—15″ channels.

Let plate be $12''\times\frac{1}{2}''$;

Area of two flanges=4.125.

Area of two webs=15.75 and $D-2t_1=14$.

Hence $m=14(6+4.125+2.62)$

$=14\times12.75=178.5.$

If the channels are turned inward the moment will, of course, be the same.

In a similar way may the effective depth and moment of resistance of any form of girders be found.

Solid Eye Beams.

Example—Floor beams $17\frac{1}{2}$ feet apart and $17\frac{1}{6}$ feet from center to center of pins. Roadway 16 feet wide in the clear. Rolling load 1280 pounds per lineal foot of bridge. Allowable strain 10,000 pounds per square inch.

A 12″, 42 pound eye beam (Carnegie No. 3) is used. Is it sufficient for the load? The moment of the beam is $45.96\times10000=459600$.

Load per lineal foot of bridge;

Flooring (pine 3″)

$3\times16=48$ ft., $48\times3\frac{1}{2}=160$ pounds.

9 joists (pine 3″×12″)

$3\times9=27$ ft., $27\times3\frac{1}{3}=90$

2 wheel guards (pine 6″×6″)

$2\times3=6$ ft., $6\times3\frac{1}{3}=20$

270

Add 1280

1550

Load on the beam

$=1550\times17\frac{1}{2}=27125$ pounds.

Weight of beam $=17\frac{1}{6}\times42=721$

Total load on beam 27846

The moment of the load

$$=\frac{27846\times17\frac{1}{6}\times12}{8}=717034.$$

Now $\frac{459600}{717034}=.64$. This shows that

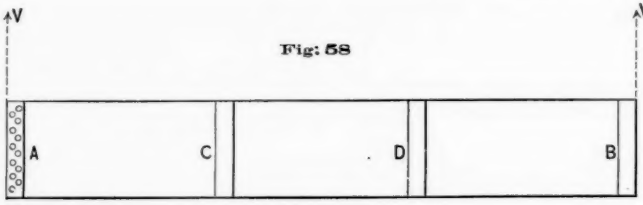


Fig: 58

the floor beam has but 64% of the required capacity. A 15″, 50lb beam has a moment of resistance = 70.6×10000 =706000, and has therefore a capacity of $\frac{706000}{711034}$=.98, or 98% of that required, and may be considered sufficient.

Complete design for a plate floor beam with cover plates for a single track railway bridge.

Let the beam be 15 feet between supports, total length 16 feet; and let AC= DB=$5\frac{1}{6}$ feet=62 inches and CD=$4\frac{2}{3}$ feet =56 inches. The ends of the track stringers rest at C and D.

Let the web plate be 28 inches deep and $\frac{3}{8}$ of an inch in thickness. The flanges alone are supposed to resist the longitudinal strains of compression and tension.

We will suppose the beams to be 16 feet apart, and the wheel spaces 7 feet; and that 24,000 pounds rest upon each pair of wheels. The train weight on a beam is therefore

$$24{,}000+2\times\tfrac{9}{16}\times24{,}000+2\times\tfrac{2}{16}\times24{,}000$$

=57,000 pounds, or 28,500 at C and at D.

We will assume the weight of beam to be 100 pounds per foot, or 1,600 pounds; and that of the track stringer 80 pounds per foot, or 1,280 pounds. Hence the external weight on the beam at C or at D is

$$28{,}500+640=29{,}140 \text{ pounds.}$$

The reaction V at A, is equal to

$$29{,}140+800=30{,}000 \text{ pounds nearly.}$$

The weight of the beam between A and C is $5\frac{1}{6}\times100=520$ pounds.

Hence the bending moment at C is

$$30{,}000\times62-520\times31=1{,}844{,}000$$

inch pounds nearly.

To proportion the flanges for the middle portion of the beam.

We will try $3''\frac{1}{2}\times3''\times\frac{1}{2}''$ angle irons (10.4 lb., 3.11 □″) with a plate $9''\times\frac{5}{16}''$.

We will use $\frac{3}{4}''$ rivets in both legs of the angles:

Area of two angles is	6.22 □″
Area lost by a rivet, is $2\times\frac{3}{4}\times\frac{1}{2}$	.75″
Net area is	5.47′
Net area of plate is $(9-2\times\frac{3}{4})\times\frac{5}{16}$	2.34″
Total area is	7.81″

For an approximate result we may assume the effective depth of plate and angles together to be equal to the distance between the lines of centers of rivets in the vertical legs of the angles.

This is approximately equal to D—h. In this case D—h=28—3=25.

We will take the allowable tensile and compressive resistances in the flanges to be 10,000 pounds per square inch.

Hence, moment of resistance

$$=10{,}000\times7.81\times25=1{,}952{,}500.$$

This is about 110,000 or 6% in excess of requirements.

We will therefore try the above angle-irons, with a plate $8''\times\frac{5}{16}''$, computing more carefully

	Square Inches.
Net area of angles	=5.47
Net area of plate=$6\frac{1}{2}\times\frac{5}{16}$	=2.03
Total,	7.50

The lever arm of angles

$=28-(3+\frac{1}{2}+\frac{5}{8})+\frac{1}{6}=24.04$ inches,

and that of the plate $=28$ "

Hence moment of resistance

$$=10{,}000\,(5.47\times24.04+2.03\times28)$$
$$=10{,}000\,(131.5+56.8)=1{,}315{,}000$$
$$+568{,}000=1{,}883{,}000 \text{ inch pounds.}$$

This is about 2% in excess of requirements, and may be considered satisfactory.

To find the number of rivets required in the vertical legs of the angle irons.

The total strain in the flanges must pass through these rivets. Hence, assuming the rows of rivets to be 25 inches apart, as above, the flange strain at C is

$$1,844,000 \div 25 = 73,760 \text{ pounds,}$$

or 36,880 pounds on each angle.

The bearing value of a $\frac{3}{4}''$ rivet through a $\frac{3}{8}''$ plate is, by Table IV., 4,220 pounds. Hence number required is $\frac{7\,3\,7\,6\,0}{4\,2\,2\,0} = 18$.

Since the rivets sustain double shear in the flanges, Table IV. shows that the resistance of the rivets to shearing is much greater than to bearing, and that the former need not therefore be considered.

Now, the lever arm of the strain on the flanges is $\frac{1}{2}(\frac{3}{8} + \frac{1}{2}) = \frac{7}{16}''$, and the moment, $36,880 \times \frac{7}{16} = 16,135$ inch pounds. The moment of a rivet is 780 inch pounds. Hence number of rivets required to resist bending is $\frac{1\,6\,1\,3\,5}{7\,8\,0} = 21$.

We will insert, say, 24 rivets in the 62 inches from A to C, spacing about $2\frac{1}{2}$ inches apart.

The Table shows that with a $\frac{3}{8}''$ plate the double shearing is equal to the bearing resistance for $\frac{1}{2}''$ rivets and over, and we have just found that the bending is nearly equal to the bearing resistance for $\frac{3}{4}''$ rivets and over.

Now, since the bearing resistance increases as the product of the diameter of rivet and thickness of plate, and the shearing resistance as the square of the diameter of the rivet, and the bending resistance as the quotient of the cube of the diameter of the rivet, divided by the thickness of the plate and the angle leg; and since the thickness of the plate and that of the angle legs increase approximately with the diameter of the rivets, it is evident that the three resistances increase or decrease approximately together.

With the plates and angles used, however, it will be found that in general, the smaller rivets are weaker for bending than bearing and the larger rivets stronger.

It is unnecessary to compute the strain at any point between C and D, for it would differ from the strain at C or D by an amount due to the weight of the beam only, which is very small.

To find the length of the cover plates.

Since the weight of the beam is small compared with the load, the flange stress or moment of flange stress increases almost uniformly from A to C.

Hence an increased section is first needed at $(5.47 \div 7.50) \times 62 = 45$ inches from A.

If, however, the end of the cover plate is placed at the above point, the angles will be strained to the allowable limit at that point, the stress will decrease quite rapidly on either side of it, and the beam will be somewhat distorted in consequence.

It is better, therefore, to extend the end of the plate from the point in question one-fourth or one-third of the distance to A.

We will use a cover plate 10 feet long, reaching from a point $2\frac{1}{2}$ feet from A to a point $2\frac{1}{2}$ feet from B.

We will use $\frac{3}{4}''$ rivets to bind the cover plate to the angles, and they should, so far as possible, be pitched half way between the rivets in the other leg of the angle irons.

It is customary to extend the cover plate, say, one and a half times its width, but the proper distance to extend the cover plate does not so much depend upon its width as upon the space between its end and the end of the beam, as above pointed out.

We have so far confined our attention to the tension flange, but the same design is surely sufficient for the compression flange, since the resistance of wrought-iron for compression is fully equal to that for tension, and the rivet holes in the compression flange need not be deducted.

The upper (compression) flange is frequently constructed with a cover plate, the lower flange with heavier angle irons, without a cover plate.

While less material is lost in the tension flange by rivet holes, without than with a cover plate, the use of a cover plate above and none below, leaves the flanges unsymmetrical. Besides, the effective depth is less without than with cover plates, and hence the advantage of the above arrangement is not so great as might be supposed. For example, the gross material in the above flange is $6.22 + 2.50 = 8.72$ square inches.

Gross material in two angle irons,
$4'' \times 3\frac{1}{4}'' \times .60''$, is..... 8.72 sq. ins.
Area lost by a rivet is $.2 \times .60 \times \frac{3}{4}$. .90 " "

Net area of angles..... =7.82 " "

Effective depth of angles

$$=28-(3\tfrac{1}{2}+.60)+.17=24.07.''$$

Now, $7.82 \times 24.07 \times 10{,}000 = 1{,}882{,}274$, which is just about the same as for the flange found above. It is generally best to use a cover plate on each flange or none at all.

To find the number of rivets in the cover plate.

The total stress carried by the cover plate is $2.03 \times 10{,}000 = 20{,}300$ pounds.

The bearing value of a rivet is 4,220 pounds. Hence, the number of rivets required between the end of the plate and the point C is

$$\frac{20300}{4220} = 5.$$

Fig. 59 shows the left half of the beam AEM, with the half cover plate EM, AE =30, EC=32, and CM=28 inches. Placing rivets 2 inches from the end of the plate and 4 inches from the middle, making the three spaces on the left 3, 4 and 5 inches respectively, and the others 6 inches, the plan of the beam will appear as in the figure. This gives more than double the number required between the end of the plate E and C, and plenty between C and M.

In case more than one cover plate is used, there must be rivets enough between the ends of the first and the second plate to take up the tension in the first plate.

The number is found precisely as above.

In the compression flange, the cover plate between any two consecutive rivets forms a solid rectangular column.

And hence the rivets should not be so far apart as to allow of any material amount of long column flexure.

The pitch of the rivets should probably not be more than about 20 times the thickness of the plate.

The reaction at the ends of the beam is 30,000 pounds.

The transverse section of the web is $28 \times \frac{3}{8} = 10.5$ square inches, the shearing resistance of which is $10.5 \times 8{,}000 = 84{,}000$ pounds, or nearly three times the amount required.

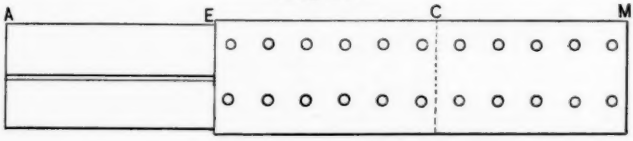
The upward pressure of 30,000 pounds at the end of the beam must also be provided for.

For this we will rivet two $3'' \times 2\frac{1}{2}'' \times \frac{3}{8}''$ angle irons to the web, one on each side, the 3" legs lying against the web.

The area of the cross section of these two angle irons is 4 square inches, which is abundant to take up a compression of 30,000 pounds.

Since the bearing capacity of a $\frac{3}{4}''$ rivet is 4,220 pounds, we will require $30{,}000 \div 4{,}220 = 8$ such rivets to transfer the strain from the angles to the web; 11 rivets are used, as shown in the figure.

Fig. 59



It is important in such cases as this to secure a firm bearing of the lower ends of the vertical angle irons upon the flanges of the angle irons of the lower flange, in order that the former may take up the reaction, and prevent the crushing of the web plate.

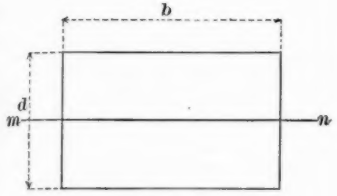
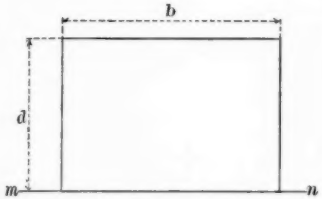
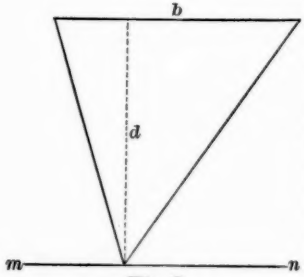
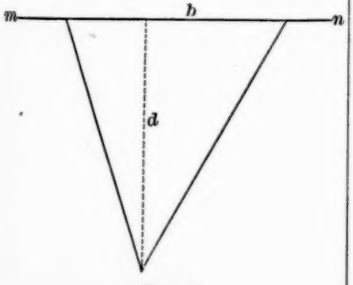
Stiffening angles similar to those used at the ends should be riveted to the web at C and D.

Since riveted work is never perfect, and since, too, the strains in the flanges are along the lines of rivet holes, which do not coincide with the *center of forces* on the angles, it is plain that there must be some strain and distortion of the flanges, not provided for in the computation.

It is well, therefore, to use an abundance of rivets.

Taking the effective depth at 28 inches, which it is customary to do, and which, we are assured, leads to "no essential error," we find the moment of resistance

TABLE I.—MOMENTS OF INERTIA AND RESISTANCE.

Form of Section.	Moment of Inertia I.	Moment of Resistance $\frac{I}{d}$
 Fig. 1	$\frac{1}{12}bd^3 = \frac{1}{12}Ad^2$.	$\frac{1}{6}bd^2 = \frac{1}{6}Ad$.
 Fig. 2	$\frac{1}{3}bd^3 = \frac{1}{3}Ad^2$.	$\frac{1}{3}bd^2 = \frac{1}{3}Ad$.
 Fig. 3	$\frac{1}{4}bd^3$	$\frac{1}{4}bd^2$
 Fig. 4	$\frac{1}{12}bd^3$.	$\frac{1}{12}bd^2$

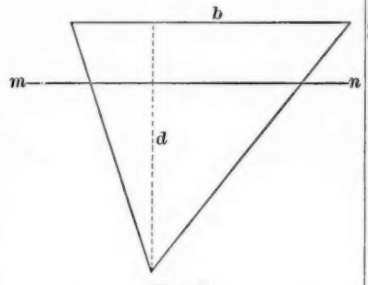
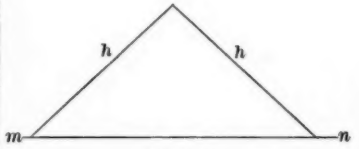
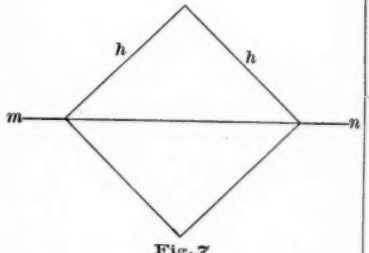
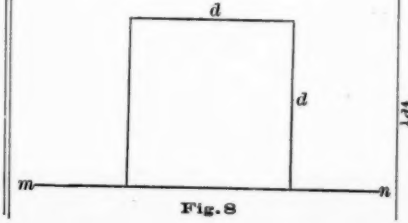
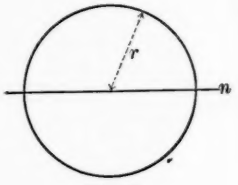
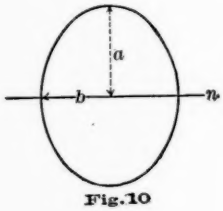
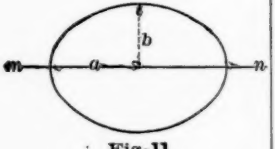
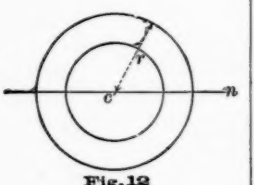
Form of Section.	Moment of Inertia I.	Moment of Resistance $\frac{I}{d}$
 Fig. 5	$\frac{1}{36}bd^3$	$\frac{1}{24}bd^2$
 Fig. 6	$.0417h^4$	$.069h^3$
 Fig. 7	$.0834h^4$	$.1179h^3$
 Fig. 8	$\frac{1}{12}d^4 = \frac{1}{12}Ad^2$	$\frac{1}{6}d^3 = \frac{1}{6}Ad$

TABLE I.—Continued.

Form of Section.	Moment of Inertia I.	Moment of Resistance $\frac{I}{d}$
 Fig. 9	$\frac{1}{4}\pi r^4$	$\frac{1}{4}\pi r^3$
 Fig. 10	$\frac{1}{4}\pi a^3 b$	$\frac{1}{4}\pi a^2 b$
 Fig. 11	$\frac{1}{4}\pi b^3 a$	$\frac{1}{4}\pi b^2 a$
 Fig. 12	$\frac{1}{4}\pi(r^4 - r_1^4)$	$\frac{\frac{1}{4}\pi(r^4 - r_1^4)}{r}$

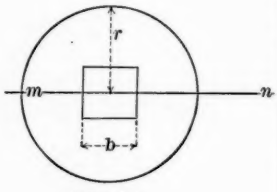
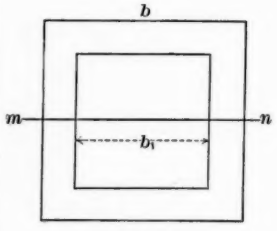
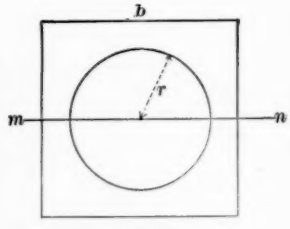
Form of Section.	Moment of Inertia I.	Moment of Resistance $\frac{I}{d}$
 Fig. 13	$\frac{1}{4}\pi r^4 - \frac{1}{12}b^4$	$\frac{\frac{1}{4}\pi r^4 - \frac{1}{12}b^4}{r}$
 Fig. 14	$\frac{1}{12}(b^4 - b_1^4)$	$\frac{\frac{1}{12}(b^4 - b_1^4)}{b}$
 Fig. 15	$\frac{1}{12}b^4 - \frac{1}{4}\pi r^4$	$\frac{\frac{1}{12}b^4 - \frac{1}{4}\pi r^4}{b}$

TABLE I.—Continued.

Form of Section.	Moment of Inertia I.	Moment of Resistance $\frac{I}{d}$
Fig. 16	$a\left(d^2-2dr+\frac{5r^2}{4}\right)$	$a\left(d-2r+\frac{5r^2}{4d}\right)$ $=a\left(d_1+\frac{5r^2}{4d}\right)$
Fig. 17	$a\left(d^2-2dr+\frac{5r^2}{4}\right)$	$a\left(d-2r+\frac{5r^2}{4d}\right)$ $=a\left(d_1+\frac{5r^2}{4d}\right)$
Fig. 18	$a\left(d^2-1.15dr+\frac{2r^2}{5}\right)$	$a\left(d-1.15r+\frac{2r^2}{5d}\right)$
Fig. 19	$a\left(d^2-.848dr+\frac{r^2}{4}\right)$	$a\left(1-.848r+\frac{r^2}{4d}\right)$

Form of Section.	Moment of Inertia I.	Moment of Resistance $\frac{I}{d}$
Fig. 20	$\frac{5}{6}d^4\ 1\ 3$ $=0.9623\,d^4$ $=\frac{5}{6}r^4\sqrt{3}$ $=0.5413r^4$	$0.9623d^3$
Fig. 21	$0.5413d^4$ $=0.5413r^4$	$0.5413d^3$
Fig. 22	$\frac{1+2\sqrt{3}}{6}r^4$ $=0.6381r^4$ $=0.8761d^4$	$0.8761d^3$
Fig. 23	$0.8761(d^4-d_1{}^4)$	$\frac{0.8761(d^4-d_1{}^4)}{d}$

$$=10{,}000\times7.5\times28=2{,}100{,}000.$$

Now (2,100,000—1,883,000)÷1,883,000 =.115, which shows an error of 11½%.

The error committed by assuming the effective depth to be equal to that of the web plate is greater without than with flange plates; it increases as h increases compared with D.

It is usually between 10 and 20%, giving an average of perhaps 15%.

The distortion spoken of above is greater with than without cover plates; hence it is better to use cover plates sparingly, even at the sacrifice of some extra material at the ends of the angles.

It is generally better, too, to use one cover plate for each flange than two or more, even though the one requires more material than the two; for, in the first place, the heavy plate between two consecutive rivets will resist far more bending, as a column, than two plates of the same combined thickness; and, again, many more rivets are required with two plates than with one.

We may now compute the weight of the beam.

We have—

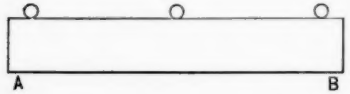
	Pounds.
1 web plate, $16''\times28''\times\frac{3}{8}''\times\frac{10}{8}$	560
4 angles, $4\times16''\times10.4$	666
2 cover plates, $2\times10\times8''\times\frac{5}{16}''\times\frac{10}{3}$	167
8 stiffening angles, $8\times\frac{27}{16}''\times6.7$ sq. ins.	121
8 filling plates, $8\times\frac{225}{16}''\times8''\times\frac{1}{2}''\times\frac{10}{8}$	73
Rivet heads (say)	33
	1,620

or 101 pounds per foot.

The weight of the beam exceeds the estimate by a few pounds only.

Should we dispense with the filling plates, which is often done, but not advisable, the weight of the beam would fall a little short of the estimate.

Fig. 60



The above design will apply equally well to the track stringer, or to any track stringer or plate girder.

In case of the above track stringer, for example, the greatest reaction at each end is $\frac{24.000\times3}{2}=36{,}000$ pounds.

The moment at the center of the stringer in inch pounds is

$$36{,}000\times8\times12-24.000\times7\times12$$
$$=1{,}440{,}000.$$

The moment of resistance of two 15″ light Carnegie eye beams is, by Carnegie or our Table above,

$$2\times70.6\times10{,}000=1{,}412{,}000.$$

This shows that two eye beams slightly heavier than the above would be sufficient for track stringers for the assumed load.

Wooden Beams.

The following Table gives the safe load, uniformly distributed, for rectangular oak or white or yellow pine beams, for a maximum fiber strain of 10,000 pounds per square inch. The table covers the sizes in general use. Observing, however, that the strength varies as the the thickness and as the square of the depth, the strength of any size may be easily obtained from some tabular size. Thus, a beam 2×16 will carry four times the load that one 2×8 will carry, or two-thirds the load that a beam 3×16 will carry.

Observing, too, that

$9^2=8^2+4^2$ nearly, $10^2=8^2+6^2$

$18^2=16^2+8^2$ nearly, and

$20^2=16^2+12^2$, etc., etc.

Table II.

Size of Beam.

Length in ft.	2×4	2×6	2×8	2×10	2×12	3×12	3×14	3×16
6	593	1333	2370	3704	5333	8000	10889	14222
7	508	1143	2032	3175	4571	6857	9333	12190
8	444	1000	1778	2778	4000	6000	8167	10667
9	395	889	1580	2469	3556	5333	7259	9481
10	356	800	1422	2222	3200	4800	6533	8533
11	323	727	1293	2020	2909	4364	5939	7758
12	296	667	1185	1852	2667	4000	5444	7111
13	274	615	1094	1709	2462	3692	5026	6564
14	254	571	1016	1587	2286	3429	4667	6095
15	237	533	948	1481	2133	3200	4356	5689
16	222	500	889	1389	2000	3000	4083	5333
17	209	471	837	1307	1882	2824	3843	5020
18	198	444	790	1235	1778	2667	3630	4741
19	187	421	749	1170	1684	2526	3439	4491
20	178	400	711	1111	1600	2400	3267	4267
21	169	381	677	1058	1524	2286	3111	4063
22	162	364	646	1010	1455	2182	2970	3879
23	155	348	618	966	1391	2087	2841	3710
24	148	333	593	926	1333	2000	2722	3556
25	142	320	569	889	1280	1920	2613	3413

Table III.

Distance between supports in ft.	Effective Depth of Girder in Inches.						
	12	14	16	18	20	22	24
10	.125	.107	.094	.083	.075	.068	.062
11	.137	.118	.103	.092	.082	.075	.069
12	.150	.129	.112	.100	.090	.082	.075
13	.162	.139	.122	.108	.097	.089	.081
14	.175	.150	.131	.117	.105	.095	.087
15	.187	.161	.141	.125	.112	.102	.094
16	.200	.171	.150	.133	.120	.109	.100
17	.212	.182	.159	.142	.127	.116	.106
18	.225	.193	.169	.150	.135	.123	.112
19	.237	.204	.178	.158	.142	.130	.119
20	.250	.214	.187	.167	.150	.136	.125
21	.262	.225	.197	.175	.157	.143	.131
22	.275	.236	.206	.183	.165	.150	.137
23	.287	.246	.216	.192	.172	.157	.144
24	.300	.257	.225	.200	.180	.164	.150
25	.312	.268	.234	.208	.187	.170	.156
26	.325	.279	.244	.217	.195	.177	.162
27	.337	.289	.253	.225	.202	.184	.169
28	.350	.300	.262	.233	.210	.191	.175
29	.362	.311	.272	.242	.217	.198	.181
30	.375	.321	.281	.250	.225	.205	.187

Distance between supports in ft.	Effective Depth of Girder in Inches.						
	26	28	30	32	34	36	38
10	.058	.054	.050	.047	.044	.042	.039
11	.063	.059	.055	.052	.049	.046	.043
12	.069	.064	.060	.056	.053	.050	.047
13	.075	.070	.065	.061	.058	.054	.051
14	.081	.075	.070	.066	.062	.058	.055
15	.087	.080	.075	.070	.066	.062	.059
16	.092	.086	.080	.075	.071	.067	.063
17	.098	.091	.085	.080	.075	.071	.067
18	.104	.096	.090	.084	.079	.075	.071
19	.110	.102	.095	.089	.084	.079	.075
20	.115	.107	.100	.094	.088	.083	.079
21	.121	.112	.105	.098	.093	.087	.083
22	.127	.118	.110	.103	.097	.092	.087
23	.133	.123	.115	.108	.101	.096	.091
24	.138	.129	.120	.112	.106	.100	.095
25	.144	.134	.125	.117	.110	.104	.099
26	.150	.139	.130	.122	.115	.108	.103
27	.156	.145	.135	.127	.119	.112	.107
28	.162	.150	.140	.131	.124	.117	.110
29	.167	.155	.145	.136	.128	.121	.114
30	.173	.161	.150	.141	.132	.125	.118
31	.179	.166	.155	.145	.137	.129	.122
32	.185	.171	.160	.150	.141	.133	.126
33	.190	.177	.165	.155	.146	.137	.130
34	.196	.182	.170	.159	.150	.142	.134
35	.202	.187	.175	.164	.154	.146	.138
36	.208	.193	.180	.169	.159	.150	.142
37	.213	.198	.185	.173	.163	.154	.146
38	.219	.204	.190	.178	.168	.158	.150
39	.225	.209	.195	.183	.172	.162	.154
40	.231	.214	.200	.188	.176	.167	.158

Table IV.

Shearing, Bending Moment and Bearing Value of Rivets. Maximum fiber strain for bending 17,500 pounds per square inch.

Diameter of Rivet in Ins.	Area of Rivet.	Single Shear at 7500 lbs. per sq. inch.	Bending Moments in inch pounds.	Bearing value for different thicknesses of plate at 15,000 lbs. per sq. inch. (=Diameter of Rivet×thickness of plate×15,000 lbs.)											
				1/4″	5/16″	3/8″	7/16″	1/2″	9/16″	5/8″	11/16″	3/4″	13/16″	7/8″
7/8	1104	828	91	1410											
1	1503	1130	144	1640	2050										
1 1/8	1963	1470	215	1880	2340	2810									
1 1/4	2485	1860	306	2110	2640	3160	3690								
1 3/8	3068	2300	420	2340	2930	3520	4100								
1 1/2	3712	2780	558	2580	3220	3870	4510	5160							
1 5/8	4418	3310	725	2810	3520	4220	4920	5630	6330						
1 3/4	5185	3890	921	3050	3810	4570	5330	6090	6860	7620					
1 7/8	6013	4510	1151	3280	4100	4920	5740	6560	7380	8200					
2	6903	5180	1415	3520	4390	5270	6150	7030	7910	8790	9670				
2 1/8	7854	5890	1718	3750	4690	5620	6560	7500	8440	9380	10310	11250			
2 1/4	8866	6650	2060	3980	4980	5980	6970	7970	8960	9960	10960	11950	12950		
2 3/8	9940	7460	2447	4220	5270	6330	7380	8440	9490	10550	11600	12660	13710	14770	
2 1/2	1.1075	8310	2877	4450	5570	6680	7790	8910	10020	11130	12250	13360	14470	15590	

We see that a beam 9 inches in depth is but a trifle stronger than two beams of the same width, 8 and 4 inches in depth respectively. The same may be said of a beam 18 inches in depth compared with two beams 16 and 8 inches in depth. A beam 10 inches in depth has just the strength of two others of the same width, 8 and 6 inches in depth respectively; and the same is true of a beam 20 inches in depth compared with two others 16 and 12 inches in depth.

TABLE V.

Bearing Value of Pins for one Inch Thickness of Plate.

Diameter of Pin. Inches.	Area of Pin. Sq. inches.	Bearing Value at 12500 lbs. per sq. inch. lbs.	Bearing Value at 15000 lbs. per sq. inch. lbs.
1	.785	12500	15000
1 1/8	.994	14100	16900
1 1/4	1.227	15000	18800
1 3/8	1.485	17200	20600
1 1/2	1.767	18800	22500
1 5/8	2.074	20300	24400
1 3/4	2.405	21900	26300
1 7/8	2.761	23400	28100
2	3.142	25000	30000
2 1/8	3.547	26600	31900
2 1/4	3.976	28100	33800
2 3/8	4.430	29700	35600
2 1/2	4.909	31300	37500
2 5/8	5.412	32800	39400
2 3/4	5.940	34400	41300
2 7/8	6.492	35900	43100
3	7.069	37500	45000
3 1/8	7.670	39100	46900
3 1/4	8.946	42200	50600
3 3/8	10.32	45300	54400
3 1/2	11.79	48400	58100
4 1/8	13.36	51600	61900
4 1/4	15.03	54700	65600
4 3/8	16.80	57800	69400
4 1/2	18.67	60900	73100
5 1/8	20.63	64100	76900
5 1/4	22.69	67200	80600
5 3/8	24.85	70300	84400
5 1/2	27.11	73400	88100
6 1/8	29.46	76600	91900
6 1/4	31.92	79700	95600
6 3/8	34.47	82800	99400
6 1/2	37.12	86900	103100

TABLE VI.

Maximum Bending Moments to be allowed on Pins for Maximum Fiber Strains of 15000, 20000 and 22500 lbs. per square inch.

Diameter of Pin in Inches.	Moment for S=15000. Lbs. in.	Moment for S=20000. Lbs. in.	Moment for S=22500. Lbs. in.
1	1470	1960	2210
1 1/8	2100	2800	3140
1 1/4	2880	3830	4310
1 3/8	3830	5100	5740
1 1/2	4970	6630	7460
1 5/8	6320	8430	9480
1 3/4	7890	10500	11800
1 7/8	9710	12900	14600
2	11800	15700	17700
2 1/8	14100	18800	21200
2 1/4	16800	22400	25200
2 3/8	19700	26300	29600
2 1/2	23000	30700	34500
2 5/8	26700	35500	40000
2 3/4	30600	40800	45900
2 7/8	35000	46700	52500
3	39800	53000	59600
3 1/8	44900	59900	67400
3 1/4	50600	67400	75800
3 3/8	56600	75500	84900
3 1/2	63100	84200	94700
3 5/8	70100	93500	105200
3 3/4	77700	103500	116500
3 7/8	85700	114200	128500
4	94200	125700	141400
4 1/8	103400	137800	155000
4 1/4	113000	150700	169600
4 3/8	123300	164400	185000
4 1/2	134200	178900	201300
4 5/8	145700	194300	218500
4 3/4	157800	210400	236700
4 7/8	170600	227500	255900
5	184100	245400	276100
5 1/8	198200	264300	297300
5 1/4	213100	284100	319600
5 3/8	228700	304900	343000
5 1/2	245000	326700	367500
5 5/8	262100	349500	393100
5 3/4	280000	373300	419900
5 7/8	298600	398200	447900
6	318100	424100	477100
6 1/8	338400	451200	507600
6 1/4	359000	479400	539300
6 3/8	381500	508700	572300
6 1/2	404400	539200	606600
6 5/8	428200	570900	642300
6 3/4	452900	603900	679400
6 7/8	478500	6380 0	717800

Plate Girders.

Table III. gives coefficients for determining the area required in flanges, allowing 10,000 pounds fiber strain per square inch of gross section.

The Table gives, opposite the length and under the effective depth, the area required for a distributed load of 1,000 pounds. Hence, to find the area required for a given load, multiply the co-efficient by the load in pounds and divide by 1,000.

For simplicity, the total depth may be taken for the effective depth; but this will of course give too large a co-efficient and too small an area. The error thus committed is approximately equal to the resistance of the web; and thus we see that, taking the total in place of the effective depth, virtually supposes the web effective in resisting longitudinal strains, though professedly ignoring it for such a purpose.

Explanation of Tables IV., V. and VI.

Rivets must be proportioned for transmitting the entire stress from one plate or group of plates, to another, taking into consideration the shearing and bending resistances, and the bearing surfaces. The requirements for bearing are frequently neglected, notwithstanding such requirements, except for the smaller rivets, frequently determine the number of rivets to be used. The bending moments of rivets usually determine the number of the smaller sized rivets to be used. For example, the bearing value of a $\frac{3}{4}''$ rivet on a $\frac{3}{8}''$ plate is 4,220 pounds, while the double shear of the same is 6,620 pounds. Examples illustrating bending will be given subsequently. If in any given case the number of rivets required to furnish sufficient bearing, much exceeds the number for shearing or bending, it may be advisable to increase the thickness of the plate for the purpose of decreasing the number of rivets.

Pins must also be proportioned for shearing, bending and bearing; but one of the two latter determines, in almost every case, the size required.

Where groups of bars are connected to the same pin, as in the lower chords of truss bridges, the bars should be of a proper size, and be properly placed so as to make the bending strain, and consequently the size of the pin, as small as possible.

Examples.—Required the thickness of metal in the top chord of a bridge that will give sufficient bearing area for $3\frac{1}{2}''$ pin having to transmit a pressure of 60,000 pounds, the allowable pressure per inch of diameter of pin for one inch thickness of plate being 12,500 pounds.

The bearing value of a $3\frac{1}{2}''$ pin for $1''$ thickness of plate $= 39{,}100$ pounds; therefore the thickness required $= \frac{60000}{39100} = 1\frac{1}{2}''$ nearly. Hence each of the two plates in the chord should be fully $\frac{3}{4}''$ thick.

The tension in the lower chord of a Pratt truss bridge, at the foot of the hip vertical, is 60,500 pounds. The chord on either side of the joint is formed of two bars $3\frac{1}{2}'' \times \frac{7}{8}''$. what is the diameter of the required pin, allowing a fiber strain of 15,000 pounds?

The pull on each of a pair of bars (two bars "packed" close together in adjacent panels) is 30,250 pounds. The lever arm of this pull is the distance between centers of the bars $= \frac{7}{4}''$. Hence the moment is $30{,}250 \times \frac{7}{8} = 26{,}470$, which calls for a pin $2\frac{5}{8}''$ in diameter.

The Chif Engineer and Inspector of Public Works in Java, M. van Geûns, has lately been on a journey through that and the neighboring islands, of which he has published an account. He speaks of the various Javan volcanoes, of which much has been heard lately, and says that since the eruption of Krakatao in 1883, the people live in comparative quiet. But this calm is only apparent, for volcanic eruptions, always numerous, are incessant. The volcanoes on the Island of Java itself manifest everywhere great activity, but not so as to produce a serious cataclysm. Smeroc, which is the heighest mountain in the island, and its neighbors Brômo and Lamonyon, are active from time to time. In 1855, for example, Smeroc overwhelmed plantations and villages on its side with eruptive matter. Merapi, in the center of the island, shows constant signs of life; lava is constantly flowing from it, smoke and steam are almost always visible at its summit, so that it is one of the active volcanoes of the world. M. van Geûns reports another curious phenomenon. After a period of extreme drought, continued rains have inundated one part of the country, while there is an absolute want of water in other places which should have it in abundance. This anomaly is attributed to the monsoons which blow irregularly, and which cause more anxiety to the Javanese than their volcanoes.

THE FLEXURE AND RESISTANCE OF LONG COLUMNS.

By L. M. HOSKINS, University of Wisconsin.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

In discussions of the flexure of columns, it is usual to employ as the differential equation of the elastic curve the form

$$\frac{d^2y}{dx^2}=\frac{M}{EI}. \qquad (1)$$

M being the moment of the applied load with reference to any point of the central line of the column, whose co-ordinates are x and y, E the coefficient of elasticity of the material, and I the principal moment of inertia of the cross-section. If we accept the "common theory" of flexure, this equation is only approximately true. The differential coefficient $\frac{d^2y}{dx^2}$ is used instead of the quantity $\frac{1}{\rho}$, the reciprocal of the radius of curvature, the true value being

$$\frac{\frac{d^2y}{dx^2}}{\left\{1+\left(\frac{dy}{dx}\right)^2\right\}^{\frac{3}{2}}}.$$

And even if the correct value of $\frac{1}{\rho}$ be used, the equation is strictly true only when all applied forces are transverse, and is therefore *not* strictly true in the case of a column.

A differential equation that is applicable to *any* condition of loading may be deduced as follows:

Taking any column, or beam, of uniform cross-section, acted upon by any forces whatever, let P denote the sum of all external longitudinal forces acting at one side of a given section, compressive forces being assumed positive; M the moment of all forces at one side of the section with reference to its central axis; z' the distance of the neutral from the central axis; z the distance of any point of the section from the central axis; ρ the radius of curvature of a fiber at the central axis; ρ_1 the radius of curvature of a fiber at the neutral axis; A the area of the cross-section; I the principal moment of inertia of the cross-section; x and y the co-ordinates of any point of the central line of the column. Since, by the theory of flexure, the fibers bend into parallel curves, it is evident that $\rho_1=\rho-z'$.

The shortening per unit length of any fiber at distance z from the central axis ($z-z'$ from the *neutral* axis) is

$$\frac{z-z'}{\rho_1}, \text{ or } \frac{z-z'}{\rho-z'};$$

and the unit compressive stress on it is

$$\frac{E(z-z')}{\rho-z'}.$$

The stress on the element of area dA is

$$\frac{E(z-z')dA}{\rho-z'},$$

and the sum of such stresses for the whole section is

$$\frac{\Sigma E(z-z')dA}{\rho-z'}=-\frac{EAz'}{\rho-z'}.$$

Hence, for equilibrium,

$$-\frac{EAz'}{\rho-z'}=P$$

or

$$z'=-\frac{\frac{P}{A}\rho}{E-\frac{P}{A}}.$$

Again, the moment of any stress

$$\frac{E(z-z')dA}{\rho-z'}$$

with reference to the central axis of the section is

$$\frac{Ez(z-z')dA}{\rho-z'},$$

and the sum of such moments for the whole section is

$$\frac{\Sigma E(z^2-zz')dA}{\rho-z'}=\frac{EI}{\rho-z'}.$$

Hence, for equilibrium,

$$\frac{EI}{\rho-z'}=M,$$

or

$$z'=\rho-\frac{EI}{M}.$$

Equating the two values found for z', gives, after reducing,

$$\frac{1}{\rho}=\frac{M}{\left(E-\frac{P}{A}\right)I} \qquad (2)^*$$

Comparing equations (1) and (2), it is seen that the use of the former involves not only the usual substitution of an approximate value for $\frac{1}{\rho}$, but also the assumption that $\frac{P}{A}$ may be neglected in comparison with E. Let us see what change this assumption introduces into Euler's formula for long columns, taking up later the discussion of equation (2). using the accurate value for $\frac{1}{\rho}$. It may be expected that in the case of the ordinary materials, and within the limits of applicability of the equation, the change will be of little importance. For since perfect elasticity is assumed in deducing the equation, it is true only within the elastic limit; and within that limit the ratio of $\frac{P}{A}$ to E is very small.

For the case of round ends, we have $M=-Py$, and (2) takes the form

$$\frac{1}{\rho}=-\frac{Py}{\left(E-\frac{P}{A}\right)I},$$

or approximately,

$$\frac{d^2y}{dx^2}=-\frac{Py}{\left(E-\frac{P}{A}\right)I}; \qquad (3)$$

while (1) becomes

$$\frac{d^2y}{dx^2}=-\frac{Py}{EI} \qquad (4)$$

For the case of fixed ends, $M=M'-Py$, M' being the restraining moment at the end, and we have instead of (3) and (4) the equations

$$\frac{d^2y}{dx^2}=-\frac{Py-M'}{\left(E-\frac{P}{A}\right)I} \qquad (5)$$

$$\frac{d^2y}{dx^2}=-\frac{Py-M'}{EI} \qquad (6)$$

Without carrying out the integrations, it is evident that the results derived from (3) and (5) may be obtained from those derived from (4) and (6) by the substitution of $E-\frac{P}{A}$ for E. From (4) and (6) may be derived the well known formulæ

$$\frac{P}{A}=\frac{E}{1+\frac{1}{\pi^2}\cdot\frac{l^2}{r^2}} \qquad (7)$$

$$\frac{P}{A}=\frac{E}{\frac{1}{4\pi^2}\cdot\frac{l^2}{r^2}} \qquad (8)$$

r being the principal radius of gyration of the cross-section. Putting $E-\frac{P}{A}$ for E gives, after reducing,

$$\frac{P}{A}=\frac{E}{1+\frac{1}{\pi^2}\cdot\frac{l^2}{r^2}} \qquad (9)$$

$$\frac{P}{A}=\frac{E}{1+\frac{1}{4\pi^2}\cdot\frac{l^2}{r^2}} \qquad (10)$$

A comparison of (9) and (10) with (7) and (8) shows that the differences are important only for small values of $\frac{l}{r}$. But these will, for ordinary materials,

---

* The following method of deriving equation (2) may seem simpler: In case there is no longitudinal loading, the reasoning is as follows: The strain per unit length on any fiber is $\frac{z}{\rho}$; the corresponding unit stress is $\frac{Ez}{\rho}$; the stress on an area dA is $\frac{Ezd A}{\rho}$; its moment about the central (also the neutral) axis of the section is $\frac{Ez^2dA}{\rho}$; and the sum of all such moments for the section is

$$M=\frac{E}{\rho}\Sigma z^2dA=\frac{EI}{\rho}.$$

In this reasoning, the unit strain on any fiber is the strain per unit *of the length before bending*. But if there is a longitudinal compressive force P, each fiber is strained before bending to the fraction $\frac{E-\frac{P}{A}}{E}$ of its original length. Hence the actual unit strain due to bending is $\frac{E-\frac{P}{A}}{E}$ of $\frac{z}{\rho}$, and the correponding unit stress is $\frac{\left(E-\frac{P}{A}\right)z}{\rho}$. This change gives for the final result

$$M=\frac{E-\frac{P}{A}}{\rho}\Sigma z^2dA=\frac{\left(E-\frac{P}{A}\right)I}{\rho},$$

which is identical with equation (2).

correspond to values of $\frac{P}{A}$ beyond the elastic limit. The smallest values of $\frac{l}{r}$ for which (9) and (10) are applicable may be found, for any given material, by substituting for $\frac{P}{A}$ the compressive elastic limit, and solving for $\frac{l}{r}$. Thus, if Q is the elastic limit, the limiting value of $\frac{l}{r}$ is for round-ended columns,

$$\frac{l}{r}=\pi\sqrt{\frac{E-Q}{Q}} \qquad (11)$$

and for fixed-ended columns,

$$\frac{l}{r}=2\pi\sqrt{\frac{E-Q}{Q}} \qquad (12)$$

Equations (7) and (8), or (9) and (10), indicate that $\frac{P}{A}$ is independent of the amount of bending. The conclusion is that the value found for $\frac{P}{A}$ is the greatest resistance of the column. For if the load be increased above this value, no condition of bending can cause a resisting moment equal to the bending moment.

It is now proposed to take up the solution of equation (2), using the accurate value of $\frac{1}{\rho}$.

For the case of round ends, (2) takes the form

$$\frac{\frac{d^2y}{dx^2}}{\left\{1+\left(\frac{dy}{dx}\right)^2\right\}^{\frac{3}{2}}}=-Ly \qquad (13)$$

where $$L=\frac{\frac{P}{A}}{\left(E-\frac{P}{A}\right)r^2}$$

The solution of this equation in terms of elliptic integrals may be effected as follows:

Multiplying through by $\frac{dy}{dx}$, and integrating,

$$\frac{2}{\left\{1+\left(\frac{dy}{dx}\right)^2\right\}^{\frac{1}{2}}}=2-L(y_1^2-y^2),$$

where y_1 is the value of y at the middle of the column. Reducing,

$$dx=\frac{[2-L(y_1^2-y^2)]dy}{\sqrt{4L(y_1^2-y^2)-L^2(y_1^2-y^2)^2}} \qquad (14)$$

Putting $\frac{y}{y_1}=\cos\varphi$, and $\frac{Ly_1^2}{4}=k^2$,

$$dx=\frac{1}{\sqrt{L}}\left(\frac{d\varphi}{\sqrt{1-k^2\sin^2\varphi}}-2\sqrt{1-k^2\sin^2\varphi}\,d\varphi\right),$$

or, with the usual notation,

$$dx\sqrt{L}=\frac{d\varphi}{\triangle\varphi}-2\triangle\varphi d\varphi \qquad (15)$$

Integrating, and determining the constant by the condition that $y=o$ when $x=o$, gives as the equation of the elastic curve

$$x\sqrt{L}=F(k,\varphi)-2E(k,\varphi)-F_1+2E_1 \qquad (16)$$

where $F(k,\varphi)$ and $E(k,\varphi)$ represent the elliptic integrals of the first and second kinds respectively, viz.:

$$\int_o^{\phi}\frac{d\varphi}{\triangle\varphi} \text{ and } \int_o^{\phi}\triangle\varphi d\varphi;$$

and F_1 and E_1 the complete integrals,

$$\int_o^{\frac{\pi}{2}}\frac{d\varphi}{\triangle\varphi} \text{ and } \int_o^{\frac{\pi}{2}}\triangle\varphi d\varphi.$$

If (15) be integrated between the limits o and $\frac{l}{2}$ for x, and the corresponding limits $\frac{\pi}{2}$ and o for φ, there results the equation

$$\frac{l}{2}\sqrt{L}=2E_1-F. \qquad (17)$$

E_1 and F_1 are functions of k, and therefore of y_1. Equation (17) shows, therefore, that $\frac{P}{A}$ is not independent of y_1, as indicated by (9), but that the load the column will support depends upon the amount of flexure. If $y_1=o$, $k=o$, and

therefore $E_1=\frac{\pi}{2}$, $F_1=\frac{\pi}{2}$, and (17) becomes

$$l\sqrt{L}=\pi,$$

which is identical with (9). Hence equation (9) gives the resistance of the column just before bending takes place. If $y_1>0$, $E_1<\frac{\pi}{2}$ and $F_1>\frac{\pi}{2}$, hence (17) shows that

$$l\sqrt{L}<\pi$$

and therefore

$$\frac{P}{A}<\frac{E}{1+\frac{1}{\pi^2}\cdot\frac{l^2}{r^2}}$$

Hence the resistance of the column is decreased by bending. It may be concluded, therefore, that equation (9), when the values of $\frac{P}{A}$ derived from it are below the elastic limit, gives the true expression for the greatest resistance of round-ended columns.

For the case of fixed ends, (2) becomes

$$\frac{\frac{d^2y}{dx^2}}{\left\{1+\left(\frac{dy}{dx}\right)^2\right\}^{\frac{3}{2}}}=-L(y-y') \qquad (18)$$

y' being a constant. Putting $y-y'=z$, (18) becomes

$$\frac{\frac{d^2z}{dx^2}}{\left\{1+\left(\frac{dz}{dx}\right)^2\right\}^{\frac{3}{2}}}=-Lz$$

Integrating, and applying the conditions that $\frac{dz}{dx}=o$ when $y=o$ and also when $y=y_1$, we find $y'=\frac{y_1}{2}$ and

$$\frac{2}{\left\{1+\left(\frac{dz}{dx}\right)^2\right\}^{\frac{1}{2}}}=2-L\left(\frac{y_1^2}{4}-z^2\right),$$

or

$$dx=\frac{\left\{2-L\left(\frac{y_1^2}{4}-z^2\right)\right\}dz}{\sqrt{4L\left(\frac{y_1^2}{4}-z^2\right)-L^2\left(\frac{y_1^2}{4}-z^2\right)^2}}$$

Putting $\frac{2z}{y_1}=\cos\varphi$, $k^2=\frac{Ly_1^2}{16}$, the last equation becomes

$$dx\sqrt{L}=\frac{d\varphi}{\triangle\varphi}-2\triangle\varphi d\varphi, \qquad (19)$$

which is identical in *form* with (15). Integrating between the limits o and $\frac{l}{2}$ for x and the corresponding limits π and o for φ, gives

$$\frac{l}{2}\sqrt{L}=2\int_o^\pi\triangle\varphi d\varphi-\int_o^\pi\frac{d\varphi}{\triangle\varphi},$$

or

$$\frac{l}{2}\sqrt{L}=2[2E_1-F_1]. \qquad (20)$$

Reasoning as before, it is seen that when $y_1=o$,

$$l\sqrt{L}=2\pi,$$

which is identical with (10). When $y_1>0$, we have $l\sqrt{L}<2\pi$,

and therefore

$$\frac{P}{A}<\frac{E}{1+\frac{1}{4\pi^2}\cdot\frac{l^2}{r^2}}$$

Hence equation (10) gives the greatest resistance of fixed-ended columns, when the values of $\frac{P}{A}$ derived from it are below the elastic limit.

In determining, from equations (11) and (12), the least values of $\frac{l}{r}$ for which formulæ (9) and (10) are applicable, Q should be taken somewhat smaller than the number usually given for the elastic limit. For, in deducing (2) it was implicitly assumed that

$$\frac{\text{unit stress}}{\text{unit strain}}=\text{constant};$$

and the point at which this ceases to be practically true is probably somewhat below the elastic limit as usually determined. In the case of wrought iron, the usual values of E and Q give about $\frac{E}{Q}=1{,}000$. This would give for the limiting values of $\frac{l}{r}$ very nearly $\frac{l}{r}=100$ for

round-ended columns, and $\frac{l}{r}=200$ for fixed-ended columns. If Q be taken smaller, these values will be increased; and, in fact, experiment indicates that they are somewhat too small.

A rational formula for the resistance of columns of lengths below the above-mentioned limits, would have to be deduced from the properties of the material when stressed beyond the elastic limit. A satisfactory treatment of this problem would be difficult, if not impossible. But since a column, if subjected to a load that stressed the material beyond the elastic limit, would in time probably rupture, this limit would seem to be the proper guide in the designing of columns of lengths below the limits above specified. Especially does this seem the rational method in the case of a material, like wrought iron, of which the elastic limit can be readily and accurately determined.

In the case of a column with one end round, the other fixed, equation (2) takes a form the accurate treatment of which is less easy. But as the usual treatment of this case is not wholly satisfactory, it may be well to consider it, using the approximate value $\frac{d^2y}{dx^2}$ for $\frac{1}{\rho}$.

If one end is fixed, a constraining couple is applied to it. If the other end is free, no equilibrating couple can act there. Neither can equilibrium be produced by longitudinal forces acting along the axis of the column. There must, therefore, be brought into play transverse forces acting at the ends of the column. Let P′ be the transverse force at the free end. Then

$$M=P'x-Py, \text{ and (2) becomes}$$

$$\frac{1}{\rho}=L'x-Ly, \text{ or approximately,}$$

$$\frac{d^2y}{dx^2}=L'x-Ly \qquad (21)$$

If (1) is used instead of (2), it takes the same form, with different values of L′ and L. To solve (21). assume

$$L'x-Ly=\alpha \sin px+\beta \cos px.$$

This is found to be a solution if $p=\sqrt{L}$.

We have then

$$L'x-Ly=\alpha \sin x\sqrt{L}+\beta \cos x\sqrt{L},$$

$$L'-L\frac{dy}{dx}=\sqrt{L}(\alpha \cos x\sqrt{L}-\beta \sin x\sqrt{L}),$$

$$-L\frac{d^2y}{dx^2}=-L(\alpha \sin x\sqrt{L}+\beta \cos x\sqrt{L}).$$

Here L′, α and β are unknown constants. Applying the conditions

$$y=o \text{ when } x=o,$$
$$y=o \text{ when } x=l,$$
$$\frac{dy}{dx}=o \text{ when } x=l,$$

we have

$$\beta=o,$$
$$L'l=\alpha \sin l\sqrt{L},$$
$$L'=\alpha\sqrt{L} \cos l\sqrt{L}.$$

The last two equations give

$$\tan l\sqrt{L}=l\sqrt{L} \qquad (22)$$

Equation (22) may be satisfied by an infinite number of values of $l\sqrt{L}$. The smallest finite value is

$$l\sqrt{L}=1.43\pi \qquad (23)$$

very nearly; and this may easily be shown to correspond to the case in which the elastic curve does not cross the axis of x between the ends of the column,—the only case of practical importance. Equation (23) gives

$$\frac{P}{A}=\frac{E}{1+\frac{1}{2.05\pi^2}\cdot\frac{l^2}{r^2}} \qquad (24)$$

or

$$\frac{P}{A}=\frac{E}{\frac{1}{2.05\pi^2}\cdot\frac{l^2}{r^2}} \qquad (25)$$

according as equation (2) or equation (1) has been used.

The usual treatment of this problem leads to the formula

$$\frac{P}{A}=\frac{E}{\frac{1}{2.25\pi^2}\cdot\frac{l^2}{r^2}};$$

and the same reasoning, using equation (2), would give

$$\frac{P}{A}=\frac{E}{1+\frac{1}{2.25\pi^2}\cdot\frac{l^2}{r^2}}.$$

These give values of $\frac{P}{A}$ about 10 per cent. greater than those found from formulæ (24) and (25).

COMPRESSED GUN COTTON FOR MILITARY USE. WITH SPECIAL REFERENCE TO GUN COTTON SHELLS.

By MAX V. FÖRSTER, Premier-Lieutenant a. D., Technical Superintendent of the Gun Cotton Factory of Wolff & Co., Walsrode, Berlin, 1886.

Translated, with the Author's permission, by JOHN P. WISSER, First-Lieutenant 1st Artillery, U. S. Army.

I.

Preface.

In continuation of our previous experiments,* we have made further investigations with compressed gun cotton, with reference to its explosive force, using larger quantities of the explosive and confining it in a closed space.

We have endeavored to establish relations in the experiments similar to those existing in military practice. With reference to the application of compressed gun cotton for military purposes, we have considered the value of the use of paraffin in connection therewith, as well as the coating of the gun cotton by dipping it in a solvent; and finally we have instituted extensive experiments on the explosion and firing of gun cotton shells, with special reference to granulated gun cotton for charging the shells.

In the recent work of Lieutenant-General Brialmont, *La fortification du temps présent, Bruxelles, 1885*, attention is called to the importance and effect of gun cotton shells, and a shell filled with gun cotton in the form of disks is described in full, so that we feel convinced that the record of our experiments in this direction will be of interest.

Our experiments with shells were carried on for several years entirely at our own suggestion and at our own ex pense, with the exception of the experi periments of firing and exploding six caliber steel shells, which were conducted in our presence by a foreign artillery.

A part of the results of our experiments was made public by the following patents taken out in Germany, in conjunction with W. F. Wolff:

1. No. 22,418. Method of exploding compressed gun cotton under water. September 1, 1882.

2 No. 24,674. Projectile containing a charge of compressed gun cotton. January 14, 1883.

A shell, the head of which may be unscrewed and the shell filled with gun cotton in the form of disks, and containing a primer, independent of the fuse, placed near the bottom of the shell.

3. No. 26,014. Method of coating pieces of compressed gun cotton, compressed nitrated wood and other forms of cellulose, partially or entirely, by treatment with a solvent thereof. March 9, 1883.

4. No. 33,867. Method of filling hollow projectiles with compressed explosives in a granulated form. May 2, 1885.

Our experiments, so far as the objects acted on are concerned, could be carried on only to the extent possible in a manufactory, but the results, we hope, will furnish data for all sorts of objects.

We are able, however, to furnish several examples of experiments with explosives on sunken ships and wrecks, carried on by us under the direction of the imperial admiralty, the imperial pilot command of Wilhelmshaven, and various other commands, as well as of private persons, which illustrate the effect of compressed gun cotton in submarine explosions in its larger relations.

We have used exclusively gun cotton prepared in the powder and gun cotton works of Wolff & Co., Walsrode. This gun cotton is used in all arms of the German Army, and has been tested by the German Navy, accepted, and a considerable quantity stored; it is supplied to many European and foreign armies and navies, and must therefore be regarded as fulfilling all the requirements of the best compressed gun cotton, and the results obtained must be regarded as applying to all good gun cotton. The gun cotton, unless otherwise specified, has a specific gravity of 1.1, and contains, on an average, 12.6 per cent. nitrogen,

* Experiments with Compressed Gun Cotton. Van Nostrand's Engineering Magazine, August, 1884.

calculated on the weight of the absolutely dry gun cotton, just as it is, that is, including chalk and foreign ingredients.

It is well known that wet gun cotton is detonated by means of a corresponding weight of dry gun cotton, and we have done this even when it is not particularly stated.

The dry gun cotton we have detonated by means of a primer containing 1 grm. mercuric fulminate from the Linden Primer Factory, in Egestorf, Linden, near Hanover. These primers act very satisfactorily, even after having been five years in store.

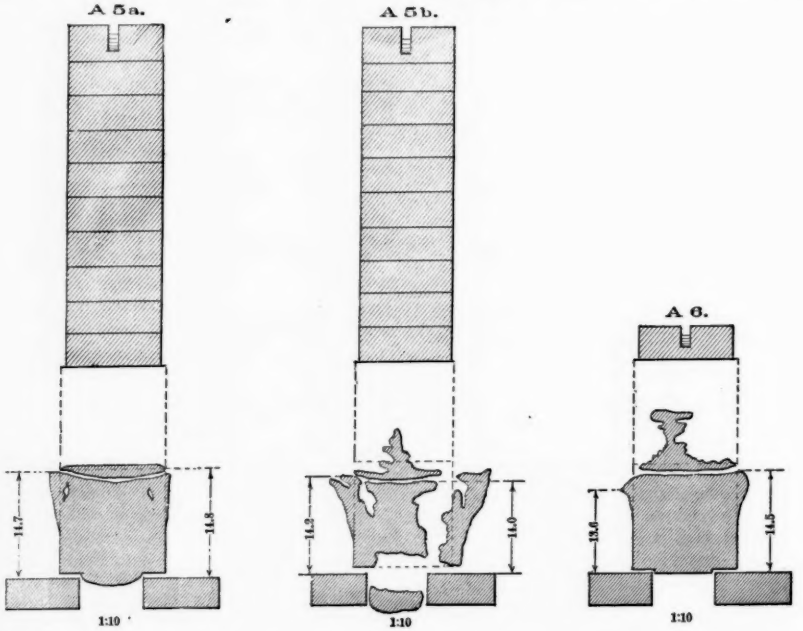
Experiment No. 5a.—6,500 grm. dry gun cotton disks, 14 cm. in diameter, and, in toto, 43 cm. high.

Experiment No. 5b.—6,500 grm. wet gun cotton disks, same weight dry plus 25 per cent. water and of the same dimensions.

Base consisting of two superposed blocks of rolled lead, 15 c.c. in volume. The lower block stood on a perforated iron plate.

The dry gun cotton destroyed the upper, the wet also the lower block.

Experiment No. 6.—A gun cotton disk, 14 cm. in diameter, 6 cm. in height,



EXPERIMENTS RELATIVE TO THE FORCE EXERTED IN THE EXPLOSION OF COMPRESSED GUN COTTON.

A. Dry and Wet Gun Cotton, not Confined, Placed on Lead Cylinders and Detonated.

Experiments Nos. 1–4.—360 grm. gun cotton, placed on lead cylinders 46 mm. in diameter and 100 mm. in height, destroyed the latter—the dry gun cotton to one-half its depth, the wet gun cotton almost completely.

weighing 920 grm., dry, containing a primer, and placed on blocks similar to those in *5a* and *5b*, destroyed them to at least the same extent, so that a charge of 900 grm. acted quite as effectively, if not more so, on the support directly underneath, as a charge of 6,500 grm., the surfaces of contact in the two cases being equal. In this experiment the result may perhaps be attributed to the effect exerted by the primer on the development of the explosive force of the gun cotton.

In the succeeding experiments the weight of the gun cotton employed was so far reduced that the object against which the force was exerted, the resistance of which was considerable, was not entirely destroyed. The charges, which were still considerable, acted in such wise that funnels with raised rims were formed in the blocks, while the upper surface of the blocks surrounding the funnels remained intact. To determine the effect, the rim was cut through vertically down to the unaffected upper surface of the block, and thus the level of the upper surface was marked on the interior of the funnel. The volume of lead displaced from the core of the block was then measured by filling the funnel to the mark with water from a glass tube graduated in cubic centimeters.

The greater the number of cubic centimeters of lead displaced, the greater the explosive force of the gun cotton.

The blocks of lead were so large (12 cm. cube), that a considerable weight of gun cotton could be employed.

GUN COTTON CARTRIDGES.—*38 mm. in diameter, 50 mm. high, 63 grm. in weight.*

Experiment No. 7.—1 dry cartridge displaced..... 27 c.c.

Experiment No. 8.—1 wet cartridge, detonated by a superposed dry cartridge like No. 7, displaced..... 36 c.c.

Experiment No. 9.—8 dry cartridges, like No. 7, placed one above the other, displaced..... 33.5 c.c.

GUN COTTON CARTRIDGES.—*60 mm. in diameter, 50 mm. high, of various weights.*

Experiment No. 10.—1 dry cartridge, specific gravity 1.1, 153 grm. in weight, displaced..... 60 c.c.

Experiment No. 11.—1 dry cartridge of the same dimensions, specific gravity 1.28, 178 grm. in weight, displaced..... 90 c.c.

Experiment No. 12.—The experiment was repeated. Weight of cartridge, 175 grm., displaced..... 90 c.c.

Experiment No. 13.—1 cartridge, as in 11 and 12, but with 18 per cent. water, containing an excavation sufficiently large to receive a dry priming cartridge weighing 32 grm., of specific gravity 1.1; the dry weight of the total amount of gun cotton employed was therefore the same as in 11 and 12, the volume as in 10, 11 and 12. Lead displaced.. 148 c.c.

Or, 2½ times as much as in 10, and 1⅔ times as much as in 11 and 12.

Experiment No. 14.—As in No. 13, but the priming cartridge weighed only 12.5 grm., specific gravity 1.1, so that 12.5 grm. gun cotton were wanting; the lower result is not, however, attributable to this. Lead displaced..... 110 c.c.

Experiment No. 15.—Cartridge as in 13 and 14, the priming cartridge, however, composed of 8 pieces, placed one on the other, 38 mm. in diameter, and weighing 63 grm. each. Primer placed in the uppermost cartridge. Lead displaced... 143 c.c.

Although, as previously shown, the action of the last cartridge in long charges, here the eighth, is less, in comparison, than that of the first, nevertheless the eighth cartridge served effectually as a priming cartridge, and forced the gun cotton detonated by it to a full development of its explosive force.

Experiment No. 16.—3 cartridges, applied as before, 60 mm. in diameter, 50 mm. high specific gravity 1.1, total weight 410 grm., all three dry, displaced..... 120 c.c.

Experiment No. 17.—3 similar cartridges, but of specific gravity 1.3, weight 488 grm., dry, displaced... 200 c.c.

Results.—Gun cotton with a specific gravity considerably above 1.1 gives higher power, and the latter increases more rapidly than the absolute weight of the gun cotton used.

It is therefore, in general, advantageous to use gun cotton of the highest possible specific gravity (when the space available for the charge is limited), although the following experiments, conducted with shells, as well as those in which the charges are not in direct contact with the object, show that, under circumstances other than those thus far considered, the superiority of the gun cotton of higher specific gravity is less noticeable.

Effect of gun cotton against objects with which it is not in direct contact, but separated therefrom by an air space.

In order to obtain data for the comparison of the following experiments, the preliminary test described under 1 was made.

1. A cylinder of gun cotton, 60 mm. in diameter, of specific gravity 1.2, 181 grm. in weight, was placed on a piece of wrought iron, 30 mm. thick and detonated.

The effect was as follows:

A trough-like depression was produced

in the iron, of the diameter of the piece of gun cotton, 8 mm. deep in the center. Besides, the effect on the lower surface of the iron was very much more marked, —the iron was nearly perforated.

2. A cylinder 60 mm. in diameter, of specific gravity 1.3, 181 grm. in weight, placed 34 mm. above a piece of iron similar to that in 1, hence, separated from it by an air space of 34 mm., made an impression 55 mm. in diameter and 3 to 4 mm. deep.

3. A cylinder 60 mm. in diameter, specific gravity 1.1, 156 grm. in weight, applied as in 2, made an impression 55 mm. in diameter, 1½ to 2 mm. deep.

Moreover, the iron received a crack in 2 and 3, running in the direction of the fibers, which penetrated to the under side.

The effect, considered as a whole, diminished in such a way that the ratio of 1 to 2 was as that of 2 to 3, the diminution in effect being quite considerable.

4. A piece of gun cotton, as in 2, specific gravity 1.3, was placed at a distance of 100 mm. from the iron, and made only traces of impressions on it.

5. A piece of gun cotton, as in 3, specific gravity 1.1, also 100 mm. from the iron, made also only traces of impressions, but even less distinct than in 4. The difference between 4 and 5 is, however, not great.

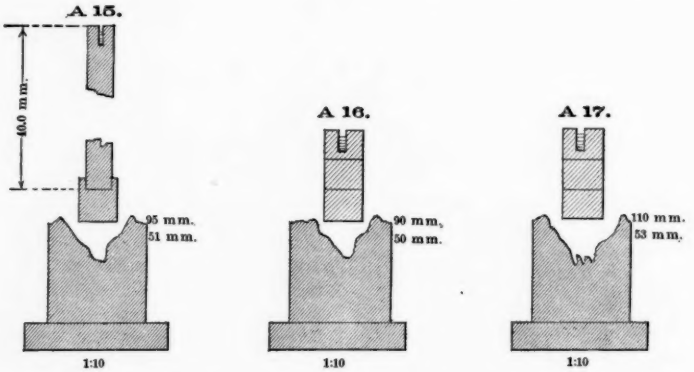
6. A charge of 254 grm. gun cotton was hung to a pine 9 cm. in diameter, at a distance of 20 cm. from the trunk and 35 cm. above the ground. On the ground under the charge was placed an oak board 25 mm. thick. The detonation peeled the bark off the pine and split a piece lengthwise from the board.

7. Another charge was similarly arranged, but of 400 grm. weight, and at only 15 cm. distance from the tree. The latter was broken and a piece was split from the board as before.

Results.—In case of an open space between the charge and the object to be destroyed, the effect is thereby greatly diminished; and in case the open space is considerable, no great difference in action is observed between gun cotton of specific gravity 1.3 and that of specific gravity 1.1.

B. Experiments with Gun Cotton enclosed in Cast Iron Shells.

The gun cotton was in the form of disks, 139 mm. in diameter and 50 mm. high, with a specific gravity of 1.1. The shells were provided with a cavity corresponding to the diameter of the disks, the side walls were 32 mm. thick, the bottom 60 mm. and the head 120 mm.



The shells were placed upright on two superposed lead blocks, each 15 c.c. in volume, such as were used in former experiments, and which were, as in the previous experiments, set on an iron plate provided with a central opening. The upper block was always more or less disturbed. The effect could be more accurately measured by the depression made in the lower block, and by the amount of lead which was forced from the bottom of the lower block into the opening of the iron plate below.

Experiment No. 1.—The shell was filled with 5,200 grm. dry gun cotton, the primer was in the upper gun cotton disk, hence on the side farthest removed from the object.

Experiment No. 2.—The shell was filled with gun cotton, containing 20 per cent. water, but of the same weight dry as No. 1. The upper piece of gun cotton was dry, and served to detonate the wet portions.

Experiment No. 3.—The charge of the shell consisted of wet gun cotton, containing 20 per cent. water, reamed out about the long axis of the shell to a diameter of 50 mm. In the head was placed a piece of dry gun cotton for detonation.

By analogy of gun cotton charges not confined, it was presumed that a very energetic effect would be produced on the object by the open central canal.

Experiment No. 4.—The shell was filled with wet gun cotton, containing 20 per cent. water; the lowermost disk, weighing 930 grm., was dry, however, and contained the detonating primer.

As shown in the diagrams B. 1, 2, 3, 4, the effect in 3, with a hollow charge, was the weakest; next in order came No. 1, the dry, then No. 2, the wet, and the effect was greatest in No. 4, in which the piece of gun cotton detonated by the primer was almost in direct contact with the object on which it was to act.

It has often appeared from the experiments that gun cotton detonated by the mercuric fulminate primer is more energetic in its action than such as, instead of being detonated directly by the primer, is detonated by other gun cotton; in this phenomenon, the distance, to which the primer acts directly, plays an important part; as soon as this distance is passed, we assume that the gun cotton is no longer exploded by the primer, but by other gun cotton.

With a view to a closer examination of the effect of the primer on the energy of the explosion, the following experiment was made:

Experiment No. 5.—Four blocks of lead, each 15 c.c. in volume, such as were used in previous experiments, were bored through the center, the diameter of the opening being 23 mm., one block not quite through, however, but only half way. The four blocks were placed one above the other, and fastened lengthwise by iron rails; the block bored only half way through at the bottom.

The channel in the four blocks, 52.5 c.m. deep, was charged with a charge of gun cotton, composed of several cartridges, 22.5 mm. in diameter and 45 cm. in length, so that the lower cartridge reached the bottom; into the upper cartridge, which was bored out for this purpose, was placed a 1 grm. primer with fuse attached, and the upper block closed with a leaden stopper, bored out for the passage of the fuse.

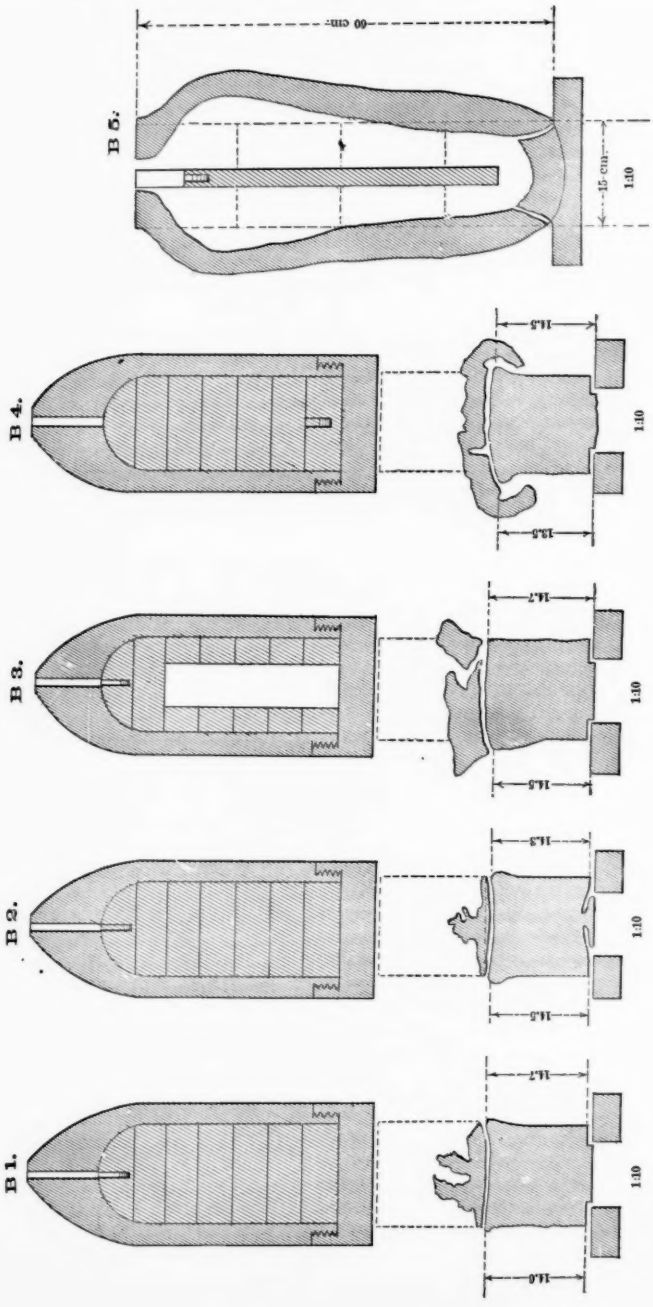
After the explosion of the cartridge the blocks were separated quite regularly into four parts, but when these parts were put together, a hollow space was seen to be formed therein by the explosion, which, in the upper quarter, where the primer had been placed, was 230 mm. in diameter, and in the lower quarter, or the one farthest removed from the primer, was 130 mm. in diameter. The spheres corresponding to these diameters are to each other as 6:1, so that it is apparent that the effect of the part detonated by the primer is six times as great as that of the lower part of the cartridge detonated by the progression of the explosion of the gun cotton.

We come to the conclusion, from these experiments, that it must be possible, by altering the physical condition of the gun cotton, or by a different method of detonation, to obtain a considerably increased effect.

The detonation of the primer develops the gases generated from the gun cotton in a very energetic form; the latter lose their force, however, against the elastic gun cotton which they meet, and cannot develop gases of the same energy as they themselves possess. Thus far it has been impossible for us to continue the experiments, using hollow lead blocks, nor to repeat them with gun cotton of specific gravity 1.3, and nitroglycerin, which is not elastic; nevertheless the experiments with charges applied externally, furnish important data.

Nor have we had opportunity to test the effect of shells filled with gun cotton, of specific gravity 1.3., against underlying objects, and, generally, objects of considerable resistance.

The difference in effect of wet and dry gun cotton is not very apparent in the ex-


B 5.
60 cm.
15 cm.
1:10
B 4.
14,5
13,5
1:10
B 3.
14,7
14,5
1:10
B 2.
14,5
14,5
1:10
B 1.
14,7
14,6
1:10

periments with shells, still, in all probability, it is considerable even in confined charges, but, in the experiments here given, its action was probably exhausted on the enclosing material itself. The bases of the shells were sufficiently thick for this to take place, 6 cm. This explanation could not be verified, because cast iron is a material which does not offer sufficient resistance to bring out the various differences in effect.

That an enclosing material, offering the same resistance in all directions, should affect the development of the energy of the compressed gun cotton, is very improbable.

If a piece of compressed gun cotton be placed on a piece of armor plate, or a piece of wrought iron of sufficient resistance, and detonated, its form will be accurately reproduced on the underlying object, and the action extends beyond this limit only so far as the parts of the iron plate, affected directly, tear along with them the parts lying adjacent. The gases produced by the detonation occupied, therefore, in the first instant, and indeed during their entire action, exactly the same form as, and no more space than, the piece of gun cotton previously occupied. How instantaneous the action is is shown by the following experiment:

If a coin be placed between a gun cotton cartridge and a wrought-iron plate, the figures and letters in relief on the coin will appear in the iron as depressions after the explosion; if, instead of the coin, a green leaf be inserted, the entire skeleton of the leaf will appear on the iron plate after the explosion. The more prominent, as well as the finer veins, protect the underlying iron, the more delicate parts of the leaf, lying between the veins, cannot afford the same protection; hence the depression under the latter is the greater.

C. Explosion of Shells on Rails.

We exploded a number of shells on objects such as occur in actual practice, and used principally granulated gun cotton for the exposive charge.

15 cm. cast-iron shells, 2½ calibers long, containing a cavity 2 liters in capacity, were filled with granulated gun cotton. After being charged the spaces between the grains were filled with liquid paraffin, as will be described in detail further on. The dry as well as the wet grains were coated by means of acetic ether. The explosive charge consisted of:

Experiment No. 1.—Dry granulated gun cotton, 1,200 grm.

Experiment No. 2.—Wet grains, containing 25 per cent. water, and 250 grm. dry grains.

Experiment No. 3.—Wet grains, containing 25 per cent. water, and 150 grm. dry grains.

Experiment No. 4.—Wet grains, containing 25 per cent. water, and 100 grm. dry grains.

Experiment No. 5.—Grains entirely coated with paraffin and 300 grm. dry grains.

Experiment No. 6.—Grains entirely coated with paraffin, and 200 grm. dry grains without paraffin, gelatinized.

Experiment No. 7.—Wet grains, containing 25 per cent. water, and a dry priming cartridge 31 mm. in diameter, weighing 35 grm.

Experiment No. 8.—Dry grains, and a priming cartridge weighing 35 grm.

Experiment No. 9.—Grains entirely coated with paraffin, 150 grm. dry grains without paraffin, and a priming cartridge weighing 35 grm.

Experiment No. 10.—A half shell, cut lengthwise, filled with 1,000 grm. gun cotton in large prisms (volume of each, 140 c.c.).

Experiment No. 11.—Two prisms, each weighing 154 grm., as in 10, placed directly on the base of a rail.

Experiment No. 12.—One such prism, as in 11, placed on a rail.

Explosions 11 *and* 12 without the employment of a shell.

Each shell received a priming cartridge 16 mm. in diameter, 9 grm. in weight, for the reception of which a space was left in the filling; in the priming cartridge was placed the primer, containing 1 grm. fulminate.

The shells were placed on three iron rails, placed with the head down, as close together as possible, as shown in the diagram (C. 12).

All the shells exploded with perfect accuracy. The effect in all the shells was approximately the same, the rails were generally broken; when this did not take place completely, a similarly great energy exhibited itself in some other manner.

The effect in No. 10 was not greater

than in the preceding ones, showing that the grains are quite as effective as the gun cotton in disks.

In 11 the rail was cut smoothly in two twice, in 12 once; in comparison with the preceding explosions the effect was greater, showing that by confining the gun cotton its effect is not increased, on the contrary, the direct instantaneous action on the object is rather weakened, a phenomenon explained by the fact that the 20 mm. thick wall of the shell removes the charge that far from the object. We call attention to the fact that we speak of the *direct* action on the object; *total* effect, acting also at a distance, must be distinguished therefrom; in the latter such small distances as 20 mm. can have no effect. This distinction also accounts for the fact that, in all experiments in which the force can act only in one direction on an object in direct contact, only relatively correct results are obtained, and that our experiments, too, at times conducted by placing the gun cotton directly on the object, and at other times confining it, furnish no uniformly accurate results.

Moreover, if 9 cylinders of gun cotton produce no more effect on the object than one cylinder (see Experiments A. 5*a*, 5*b* and 6), it does not follow that in the first case more total energy, corresponding to the weight, was not developed. At all events, even considering exclusively the effect, wet gun cotton will have preference over dry, in case it is desired to destroy, by means of externally applied unconfined charges, such objects as walls, arches, iron plates, etc., where the surface of contact between the gun cotton and the object to be destroyed is the largest possible.

Experiment No. 13.—A shell, filled with grains entirely coated with paraffin. A priming cartridge, 31 mm. in diameter, 65 grm. in weight, placed in a space left vacant for it in the filling, failed to detonate the filling of the shell. There was a partial combustion of the charge.

Experiment No. 14.—A shell, filled with grains entirely coated with paraffin, and containing a priming cartridge 31 mm. in diameter, but weighing 100 grm., detonated perfectly.

In case grains composing the filling of the shell are not bound together by means of melted paraffin, a very much heavier, and therefore larger, priming cartridge is necessary for detonation than if this is the case.

Experiment No. 15.—A 21 c.m. cast-iron shell was filled with 4,200 grm. dry granulated gun cotton, and placed on a support formed of a double row of rails. Five iron rails were placed side by side on two wooden skids, four rails were placed between the first named rails. The skids were 1 meter apart, the rails therefore had a bearing of 1 m.

The shell was covered with earth to a depth of $\frac{1}{2}$ m. The action was very considerable; all the rails were broken, most of them at several points, and in addition a depression was formed in the ground $\frac{1}{2}$ m. deep. A bomb-proof covering can, therefore, no longer be made in this way.

D. Action of Gun Cotton and Gun Cotton Shells in Earth.

Experiment No. 16.—A 15 c.m. shell, filled as above with granulated gun cotton, buried 1 m. deep in the earth, produces in light soil as well as in somewhat heavy soil (sandy clay) a cone:

60 cm. deep and 2 m. in diameter.

Experiment No. 17.—A 15 cm. shell, filled with 2,100 grm. ordinary gunpowder, produces a cone:
50 cm. deep, 2 m. long, and $1\frac{1}{2}$ m. broad.

Experiment No. 18.—A 15 cm. steel shell, 6 calibers long, filled with 8.9 kg. granulated gun cotton, wet, containing 25 per cent. water, 1 kg. dry grains, and a priming cartridge weighing 35 grm., so buried that the head was 1 m. under the surface, the base $\frac{1}{4}$ m., made a funnel:

1.3 m. deep and 4 m. in diameter.

(See diagrams).

E. Comparative Experiments with Granulated Gun Cotton and Gun Cotton Disks.

The earth in which the explosions took place was light, clayey, sandy soil.

Experiment No. 19.—A tin canister, 3 calibers long, $7\frac{1}{2}$ liters in capacity, filled with:

6300 grm. wet granulated gun cotton, } 8 mm.
300 " dry " " " } cube.
50 " priming cartridge,

5620 " = total dry weight,

was buried so that one end was 1.2 m.

under the surface, the other 0.9 m.; it formed a cone in the explosion,

1.10 m. deep, and 3.30 m. in diameter.

Experiment No. 20.—An explosive charge of the same form as in Experiment 19, but composed of disks of wet gun cotton, 8.3 kg. in dry weight, and furnished with a 50 grm. priming cartridge, was buried as in Experiment 19; it formed a cone in the explosion,

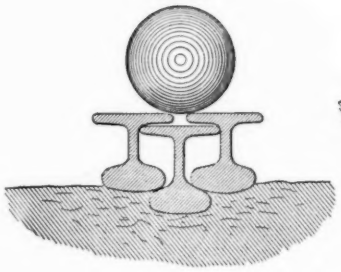
1.30 m. deep and 4.10 m. in diameter.

disks, 16.6 kg. in dry weight, provided with a priming cartridge weighing 50 grm., buried as in Experiment 21, formed a cone, in the explosion,

1.56 m. deep and 5.1 m. in diameter.

A piece of wrought iron 3 cm. thick, 10 cm. square in surface area, which, in the first two explosions lay close under one corner of the charge, in the second two explosions 15 cm. below the charge and parallel to its side wall, separated

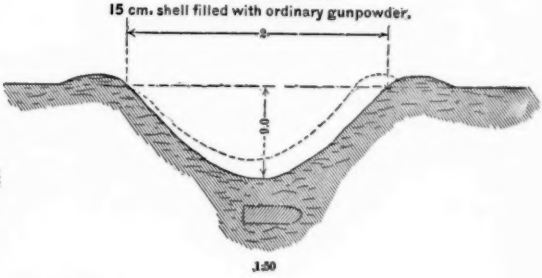
C. 12.



D. 16 and 17.

CONES OF EXPLOSION.

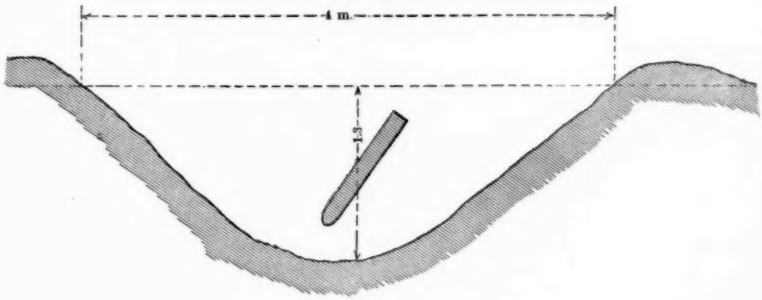
15 cm. shell filled with ordinary gunpowder.



1:50

D. 18.

A 15 cm. steel shell, 6 calibres long, with 8 kg. granulated guncotton.



1:50

Experiment No. 21.—A tin canister, 6 calibers long, 15 liters in capacity, filled with 11,150 grm. dry granulated gun cotton (8 mm. cube in volume, cubic weight 0.75) and a priming cartridge weighing 50 grm., was buried so that one end lay 1.2 m. deep, the other 0.6 m., and formed, in the explosion, a cone:

1.58 m. deep and 4.45 m. in diameter.

Experiment No. 22.—An explosive charge, composed of wet gun cotton

from it by earth, was, in Experiments Nos. 19, 21 and 22, compressed to an equal degree, but in No. 20, somewhat more than in the others. In Experiments 19 and 20, the iron lay, as remarked, immediately against the charge, and, under these circumstances, the disks were more energetic in their action than the grains.

Experiment No. 23.—A piece of iron rail, 0.5 m. long, 10 cm. broad in the base, 12 cm. high, was placed in a ditch

1.25 m. deep, resting on two pieces of fir, 10 square centimeters in cross-sections, so as to leave 25 cm. between bearings. Earth was thrown over the rail to a depth of 25 cm. above the head. A tin canister, like the one employed in Experiment No. 19, filled with 5,620 grm. dry grains and a 10 grm. priming cartridge, was placed on the earth with its axis perpendicular to that of the rail, and the ditch filled up to the surface. The canister was exploded—it cut the rail squarely across, dividing it into three parts, and besides, the base of the rail was driven 1 cm. deep into the wood. The pieces of wood were otherwise uninjured. The cone of explosion was:

1.10 m. deep, 3.10 m. in diameter.

The pieces of rail and the strips of wood were found at a depth of 1.50 m. under the surface.

Experiment No. 24.—A charge of wet gun cotton disks, of the same dimensions as the above-described tin canister, 8.3 kg. in dry weight, and provided with a 50 grm. priming cartridge, was applied as in Experiment No. 23 and exploded.

The iron rail was broken in almost the same manner as in No. 23, except that there were only two pieces, in each of which a piece was broken off from the head of the rail near the middle. The base of the rail did not penetrate into the wooden supports, but the latter were cut squarely and smoothly in two. They evidently offered less resistance than in Experiment No. 23. With the exception of this break the strips of wood sustained no injury.

The cone of explosion was:

1.5 m. deep and 3.5 m. in diameter,

hence, somewhat larger than in Experiment No. 23. The pieces of rail and the strips of wood were found buried at a depth of 1.65 m.

The charges Nos. 23 and 24 broke up the iron rails at a depth of 45 cm. below them, and threw out cones of explosion to a depth of 40 and 80 cm. respectively. The pieces of rail and the wooden supports were found pressed 90 cm. into the ground, and the sandy earth was ground to dust to the same depth.

This experiment shows that gun cotton in both forms acts not only when in direct contact, but with great force even at considerable distance.

From the comparative experiments it appears that in sum total the action of equal volumes of granulated gun cotton and gun cotton disks is the same; the excess in weight of over a third has no effect, especially when considerable weights are used, and the object to be destroyed is not in direct contact with the charge.

Whether, with other objects and under other circumstances, the excess of weight of the charge when disks are used over that of grains, will be made effective remains undetermined, but we believe from all the preceding experiments that we are forced to the conclusion that this can only take place to a slight extent.

We are furthermore of opinion that it is very doubtful whether, by the use of heavier and more sudden explosives, as, for instance, explosive gelatine, mixtures of the nitrates of benzole and aniline with nitric or hyponitric acid, in shells, a greater effect will be obtained.

In actual firing, the shells will rarely be in direct contact with the object which they are to destroy, but will more generally be some distance from it; *e. g.*, in case of arches and armor plates they will not lie in contact therewith along their entire length, but will either not be in direct contact at all or but very slightly, and at the smaller distances is just where the degree of suddenness of action of an explosive is most apparent.

In case of shells with thick cast-iron walls, the increased suddenness of action will probably have no other effect than to pulverize the walls to dust—an effect in many cases not at all desired.

It will be necessary, however, to test the various explosives under circumstances which resemble actual practice, in order to obtain comparative results of their power and action.

We will quote here a few examples from the above mentioned work of Lieutenant General Brialmont:

Ordinary 21 cm. steel shells, containing a charge of 14½ kg. of gunpowder, fired at an elevation of 45° from the Krupp 21 cm. forged mortar, penetrated from 2 to 2.60 m. into the sandy earth of the firing ground at Meppen, and threw out elliptical cones of explosion—

1.20 to 1.40 m. deep.
3.20 to 4.80 m. long.
3.20 to 4 00 m. broad.

Fired at 28° and 60° elevation, the action was less. A steel torpedo shell, 6 calibers long, containing a charge of 36 kg. of gunpowder, fired at 35° elevation, produced a cone of explosion,

2.40 m deep and 4.80 m. in diameter,

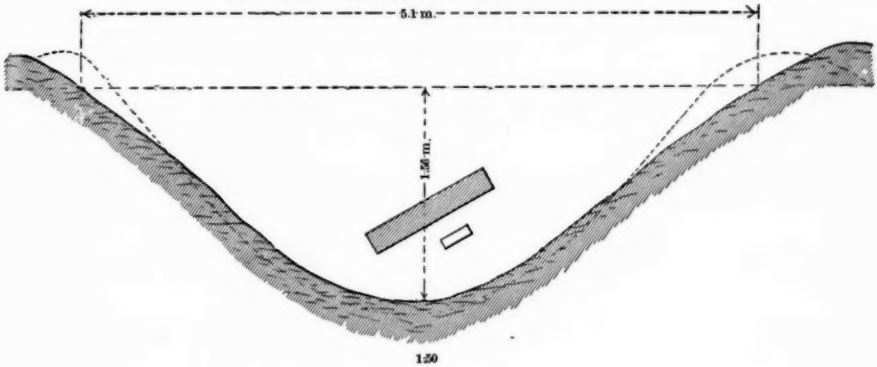
corresponding to a mean displacement of 15 cubic meters of earth.

Arches, constructed of the best béton, 1.45 m. thick, require the following thicknesses of sandy earth to protect them against various projectiles fired from the 21 cm. mortar:

E. 21 and 22.

CONES OF EXPLOSION.

16 kg. guncotton in disks, equal quantity granulated guncotton.

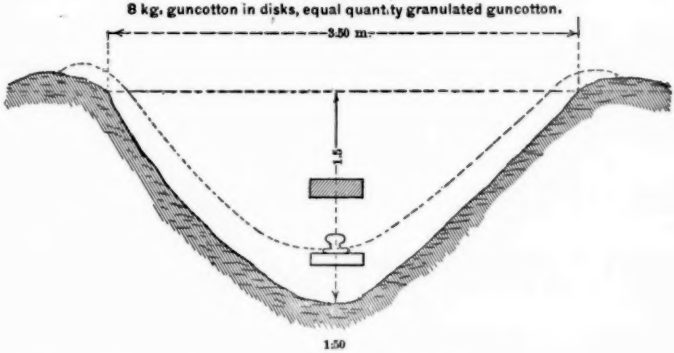


1:50

E. 23 and 24.

CONES OF EXPLOSION.

8 kg. guncotton in disks, equal quantity granulated guncotton.



1:50

1.00 to 2.20 m. deep,
3.20 to 5.00 m. long,
2.60 to 5.00 m. broad,

corresponding to a mean displacement of earth of 7 cubic meters.

The 21 cm. steel gun cotton shells penerate 4 m. deep, lying nearly horizontal, and throw out cones of explosion,

Ordinary shells,	: 2.50 m.
Steel shells, charge 14½ kg. gunpowder	: 3 to 3.50 m.
Torpedo shell filled with gun cotton	: 5 m.

But this thickness of earth covering of 5 m. cannot be attained in practice, as the fortification works will have to be too high and too costly. It is, therefore, pro-

posed to omit the earth covering entirely, and to replace it by a layer of granite or porphyry 0.80 m. in thickness, or by a bed of Portland cement 1 m. to 1.20 m. in thickness.

The experiments in Silberberg in 1869 showed, however, that even this covering will not suffice against the projectiles of the forged mortar charged simply with gunpowder, as these projectiles produced depressions of $\frac{1}{2}$ to $\frac{2}{3}$ m., so that a second shell striking the same point would penetrate the arch.

Lieutenant General Brialmont thinks, therefore, that it is not possible to propose anything definite on this subject as yet, but considers it preferable to construct the arches of the best béton, made 1 to 1.50 m. thick, and covered with at least 3 m. of earth. In case this is not sufficient, a part of the earth must be replaced by béton, or the earth covering must be increased, or an arch of sheet-iron may be inserted under the béton arch, which last is the simplest and cheapest method.

This, it is evident, approaches the armored turret.

We believe, however, that even this may be greatly damaged by means of large charges of gun cotton.

From all this it is evident that Lieutenant General Brialmont considers the power of the gun cotton shell, and its effect on the future construction of earthworks, as very great.

Submarine Explosions with Compressed Gun Cotton.

Explosion of the Iron Tug-boat Mathias Stinnes I., Sunk in the Rhine near the Railroad Bridge of Rheinhausen, below Duisburg.

Conducted by the author and engineer Math. Rossenbeck.

The tug-boat was a strong iron vessel, dating from the earliest times in which such vessels were built, constructed es pecially solidly in all its parts.

She lay with the stern 200 m. from the railroad bridge, which stood on massive piers, and 100 m. out from the right bank of the Rhine, extending thence with its entire length down stream almost in the direction of the current. The stern at mean low water was about 2 m., the bow about 6 m. under water.

The vessel was to be cleared away to a certain depth of water, so that evidently the stern and center had to be removed. The current is so strong that a diver cannot descend without assistance.

A wooden Rhenish flat boat was therefore so arranged that an iron cylinder was laid square across its deck, containing on the end extending over the flat boat an iron ladder, which could be turned in its support. When the ladder hung free vertically it was held by a hand screw, but it could also be rested on the sunken vessel, on parts which had fallen off, or on the flatter parts of the river bottom, and rose in all cases 2 m. above the shaft. On the ladder a shild $\frac{2}{3}$ m. broad was fastened, which diverted the current from it. The ladder and shield could be raised and lowered by means of a hand-screw. By means of the ladder the diver could reach the vessel, and, protected by the shield, could work readily, mostly with the left arm.

A second flat-boat of the largest kind was provided with a solid deck and a crane, by means of which and an iron chain the parts separated by the explosions were raised.

Although large charges could not be used on account of the proximity of the railroad bridge, on which account heavy shocks had to be avoided, they would have been of no avail, but would more likely have been detrimental.

No charge, however large, even if 1,000 kg. of the most powerful explosive had been detonated at once, would have destroyed the vessel in such a way that the separated parts could be raised and removed. It would have left a conglomeration of parts of the vessel which, adhering firmly, would not have permitted the removal of the separate parts or the work of the divers.

The question was how to remove separate parts by charges not too great, and then to raise these parts by means of the crane on the flat boat. Wooden chests were therefore charged with 10 kg. compressed gun cotton, and used either separately or occasionally two at the same time.

The diver descended to the vessel, placed the charge in position, which often required hours on account of the strong current, ascended; the ladder was raised, the flat-boat went out to the middle of the

stream, and the explosion was effected by electricity.

The boat returned, the diver descended, fastened a chain to the loose parts of the vessel, an operation which again required several hours, on account of the exceedingly great difficulties, and an attempt was then made to raise the parts, which generally succeeded. Often the attempt failed, however, as the parts were still fast bound to the vessel, and the strong crane could not tear them away.

The iron planks, the ribs, the wheel, gradually the boiler, parts of the wheels, parts of the shaft and the machinery appeared in turn. The shaft was a cylinder of the best steel, 15 cm. thick, and was acted on by a double charge, hence by 20 kg. gun cotton, cutting it across in several places.

Great as was the action of the gun cotton, over 100 explosions, in which 1,200 kg. gun cotton were used, were found necessary to clear the water to the required depth. The greater part of the stern of the vessel was removed, the rest was forced into the sand of the stream by the force of the explosions; the bow of the vessel till beyond the wheel shaft was little disturbed; it lay, however, below the required depth of water.

It is shown again, in this example, that the annihilation of the vessel by means of charges of explosives is entirely out of the question; iron constructions are particularly difficult to remove, unless they are raised after the explosion or the force of the explosion pushes them into the ground.

To sink a floating vessel is quite another matter.

Charges of 20 kg. of gun cotton, applied externally to a suitable part of the vessel, and lying in direct contact, will burst through the sides of the vessel, but whether they will so disturb it as to make it sink is a question. So far as relates to its action at a distance, we have observed that in explosions in deep water, at a distance of 100 m. from a charge as much as 100 kg. in weight, only a light shock is given to floating material, such as vessels, and that, on the contrary, the shock produced by such an explosion is transmitted through the solid earth to considerable distances, 500 to 800 m., to other solid substances standing on the ground, such as buildings, for instance.

Wooden vessels are easily destroyed by explosion, because after the explosion they are removed by the water, by ebb and flood tide, or by other currents.

We have destroyed a large number of such sunken vessels on the coasts of the North Sea, and at the mouths of the Jade and Weser.

Charges of 100 kg. of gun cotton each, placed in long chests, were lowered to the wreck, or, when possible, fastened by divers to the side-walls of the wrecks, and exploded.

In the case of small vessels, two or three well-applied charges are sufficient; in the case of larger vessels, considerably more are required.

Explosions at the Adlergrund.

In the Baltic Sea, between Bornholm and Rügen, lies the Adlergrund, a shoal formed by large rocks lying on the bottom of the sea. At the shallowest places the royal government, with a view to increasing the depth of water, had some of the rocks removed by vessels furnished with cranes.

Divers went down, fastened chains about the rocks, or attached clamps to them; the rocks were then raised. In order to break up the rocks and to render more easy the attachment of the lifting machinery, many charges of 10 kg. gun cotton each were placed on the bottom of the sea, to a depth of 4 to 6 m., and detonated. These explosions usually loosened from two to four blocks, each about 2 cubic meters in volume, and forced them completely out of their original position, so that they could be easily raised.

Rock-blasting in the Rhine, with a View to Deepening the Channel between Bingen and Coblenz.

In many places rocks at the bottom of the Rhine form shoals which impede navigation, the best known and most dangerous of which is the "Bingerloch." From rafts and vessels a series of holes is bored in the rocky bottom, 1 to 2 m. deep, according to the amount of rock material to be removed; these are filled with gunpowder, tamped with sand, and the charge fired. After 10 or 20, or even more blasts, vessels provided with div-

ing-bells are run over the spot, the diving bell is lowered, and, by means of picks and bars, the rocks are broken loose, and are then raised through the diving bell to the surface and loaded into vessels held ready for the purpose.

We are of the opinion that if, in place of the gunpowder, *sudden* explosives are used, the work of removing the débris, which now involves the principal cost, will be greatly simplified and rendered cheaper. It is also necessary with gunpowder to deepen the bore-holes considerably below the point to which it is desired to remove the rock; fired with sudden explosives, the rock will be removed to the bottom of the boring, whereas by the use of gunpowder the lower third of the bore-hole remains intact. The sudden explosives are not used, because people still fear those who decry them, saying that a part of the explosive may remain unexploded, and when the diving-bell is lowered and the workmen proceed to loosen the rocks, may give rise to after-explosions, produced by the shocks in striking it, which may cause serious accidents.

This may be true of nitro-glycerine preparations, which are not rendered inexplosive by penetrating water, but in the case of gun cotton the cartridges, as the author has stated in his previous article, may be easily so arranged that, after a certain time, say 24 hours, they will become thoroughly wet and rendered inexplosive and perfectly safe, as well from the explosive priming cartridge, which may still remain, as from the shocks of the tools.

Although advantages are gained by the use of compressed gun cotton in such work, we are nevertheless of the opinion that neither gun cotton nor any other sudden explosive can act so as to dispense with the boring of the bore-holes.

Externally applied charges do not, even in case of considerable depth of water, which acts as a kind of tamping, act so strongly, but that the cost of explosives will be too great.

We can conceive of an advantageous method of carrying on the work with externally-applied charges, without the use of bore-holes, only in case large surfaces of rocks are to be removed to but slight depths, perhaps to 10 or 15 cm., in which case bore-holes would even act disadvantageously. The entire work of preparing the borings and the removal of the rocks is saved, and thus, in spite of the large amount of explosives employed, a relatively cheaper and more rapid work is obtained.

EXAMINATION OF A DEPOSIT FROM THE CHANNEL WAY OF THE U. S. S. RICHMOND.

By CHARLES E. MUNROE.

Written for VAN NOSTRAND'S MAGAZINE.

THE specimen examined was received from P. A. Eng. A. B. Canaga, U.S.N., with the following statement:

"The two Martin's vertical water tubular boilers of the Richmond are constructed of wrought iron with composition tubes. The entire area of the tubes in contact with the water is 5,208 square feet. The copper steam pipe leading to the two engines is 40 feet long and 1 foot in diameter. The copper exhaust pipes leading from the engines to the condenser are each 10 feet long and 15 inches in diameter. The surfaces in the cylinder and valve chest subject to friction of metal on metal are all cast iron; and the area of this rubbing surface for piston and slide valves is 116 square feet. The steam after being exhausted from the engines is condensed in a Newell's surface condenser, the condenser tubes being of composition and tinned. The area of the condensing surface is 3,970 square feet. The condensed steam falls to the bottom of the condenser and is removed through the 'channel way' by the air pump. The sediment of which you have a sample was taken from this 'channel way,' and about 12 bushels of this muck-like sediment were removed

at the time your sample was taken. This quantity had accumulated while the ship steamed about 11,000 miles. The principal lubricants used were olive and sperm oils, but some tallow was also used. The deposit, when removed, was black with some brownish spots. It was of a slimy consistency, with some little balls, which by the swash and agitation produced by the air pump, had become more solid in their consistency."

The substance as I received it had an earthy luster and was in the main of a dark brown color, but it was interspersed with portions having the ordinary color of iron rust. The greater portion was in the form of a powder, but there were some nodular masses, which, when broken open, displayed a black color and a metallic luster. No portion of the mass gave any evidence of metallic properties when hammered on an anvil, but it was highly magnetic, and it was found possible, when finely powdered, to roughly separate about 80 parts by the aid of a magnet. It was neutral to test paper. A portion soluble in water gave reactions for sodium, calcium, copper, sulphuric acid and chlorine. A portion soluble in ether showed fatty salts. A portion soluble in muriatic acid gave iron and copper. The residue showed graphite and silica. The quantitative results from the analysis of an air-dried sample may be summed up as follows:

		Per cent.
Loss over H_2SO_4 (water)		8 32
Soluble in water	(NaCl. $CaSO_4$, &c.)	8.36
Soluble in ether	Fatty substances	9.62
	Fe_2O_3	.22
	CuO	.07
Soluble in HCl	Fe_3O_4	49.79
	Fe_2O_3	11.21
	CuO	5.09
Insoluble residue	Graphite	6.31
	Silica, &c.	1.85
		100.84

SEWER VENTILATION.

By GEORGE RICHARDSON STRACHAN, Assoc. M. Inst. C.E.

From Selected Papers of the Institution of Civil Engineers.

This paper contains a record of experiments at Chelsea on sewer-ventilation by down-draughts from cowls.

The experiments are not put forward as novel, but only as accurate observations under known conditions.

The sewer experimented on is in Jubilee Place, Chelsea. It is an egg-shaped brick sewer, 3 feet 9 inches by 2 feet 6 inches, with an inclination of 1 in 100. At the highest part it terminates in a dead-end, and at the other end joins a main sewer of the metropolitan system. At a point of 600 feet from the dead-end a head-wall is built in the sewer, and under it a dip trap to pass the sewage out. A safety-valve is fixed in the head-wall, to provide a means of discharge in the event of the dip-trap ceasing to act. The sewer is fairly well built, and receives the sewage of forty-four ordinary dwelling-houses, and the road-water from eight gulleys. The mouth of each of these drains is provided with a block-flap. The sewer was thus an elongated vessel, with a capacity of 4,300 cubic feet. The roadway above is practically level. Near the center of the length of the sewer a 15-inch pipe is inserted at springing-level, and is connected to a shaft against the side of a house. The shaft terminates at the parapet wall, and has on the top a lobster-back cowl, so arranged as to present its mouth to the wind. The mouth of the cowl is 15 inches in diameter, and the throat 9 inches in diameter. The height of the cowl above the road is 32 feet. At the dead-end a 12-inch pipe connects the sewer to a similar shaft against the side of a house opposite. This shaft terminates at a height of 22 feet above the level of the road, and is made to resemble a chimney-stack, surmounted with a 9 inch chimney-pot. At the lower end a 12-inch pipe connects the sewer to a shaft against the front of a house opposite, which terminates at the parapet with an open mouth, at a height of 31 feet above the level of the street.

The action of the system is simple. The wind, in passing the center shaft, turns the mouth of the cowl towards it,

and forces air down the shaft and through the fifteen-inch pipe into the sewer. It then divides into two currents, one passing down the sewer and out by the shaft at the lower end, and the other up the sewer and out by the shaft there.

Four air-meters were used to measure the velocities of the air entering and leaving the sewer. One was placed in the mouth of the downcast pipe in the center, where it joins the sewer; one in the mouth of the upcast pipe, where it joins the sewer at the lower end; one similarly at the high end, while the remaining one was used as a check-meter at each of these points in rotation. In every case the author entered the sewer and took the observations.

The following table shows the results. The experiments commenced on the 26th of February, and terminated on the 11th of April, both in 1885:

Number of Experiment.	Duration of Experiment in Days.	Average Velocity of Wind in Miles per Hour.	Volume of Air entering Sewer in Cubic feet per Minute.	Number of Minutes taken to fill and empty Sewer with air.	Number of times per Day Sewer was filled with air.
1	1	18.4	113	38	38
2	3	9 6	126	34	42
3	4	11.3	117	37	39
4	7	11.5	161	27	53
5	7	10 3	136	32	45
6	7	10.6	140	31	46
7	8	11.3	150	29	50
8	7	13.0	180	24	60
8	44	12.0	140	31.5	46.6

The fact that a sewer of this capacity had its gaseous contents changed every thirty-one and a half minutes during forty-four days, by the force of the wind on a self acting cowl, will probably be considered a satisfactory one. As a matter of fact, one-third of the theoretical volume of air which would have passed through the throat of the cowl at the velocity of the wind, if there had been no resistance or loss by friction, did actually pass through the sewer.

The influence of this volume of air on the interior of the sewer is beneficial. Instead of the slimy coating of bluish-white matter that adheres to the crown and sides of sewers ventilated by openings in the roadway, there is dryness for at least 100 feet on each side of the downcast shaft, and then a gradually-increasing dampness is found until the upcast shafts are reached. At these points the crown and sides of the sewer are damp, but the moisture is clean as compared with that of an ordinary sewer.

The air passing out of the upcast shafts has a very slight smell of sewer-gas. No complaints have been made as to it, either by the occupiers of the houses against which the shafts are placed, or by the neighbors, or by persons using the street.

The method of forming the shafts deserves mention. They are built against the walls of the houses, and are made of concrete. The pieces are moulded to a rectangular gutter-shape with a face 12 inches long and sides 6 inches long, so that when placed against the wall which forms the fourth side, a space 12 inches by 6 inches is enclosed. The sides are 1 inch thick. Near the end of each of the short sides a hole is moulded vertically through the piece, so that when the pieces are placed against the wall it exactly coincides with the eyehole of a holdfast driven into the wall. A stout wire is passed through these holes and eyes, and by this method the pieces are threaded to the building. The joints are made good with cement. As the outside of the shaft is marked to correspond to the courses of brickwork, it looks a part of the house, presenting the appearance of

a pier. Where necessary, mouldings are placed to further improve it.

t occurs to the author that the system might be usefully applied by fixing a cowl and shaft, of suitable sizes, at the rear of houses, connected with the house-drains. The air would pass through the house-drain into the sewer, and out of upcast shafts placed at suitable intervals. By this means the house-drains, as well as the sewer, would be ventilated. This method would do away with the necessity of the deep siphons now fixed in house-drains to protect the house from sewer-gas, which the author has occasionally found, in small property, to become stopped.

WATER PURIFICATION—ITS BIOLOGICAL AND CHEMICAL BASIS.

By PERCY F. FRANKLAND, Ph.D., B.Sc., (Lond.), F.C.S., F.I.C., Associate of the Royal School of Mines.

Proceedings of the Institution of Civil Engineers.

II.

DISCUSSION.

Sir Frederick Bramwell, President, said the paper dealt with a subject the importance of which was year by year more recognized, and which had received much attention resulting in a practical end. He wished to remind the members that during the last two or three sessions papers had been read on the same subject, and many gentlemen competent to speak upon it had given their views at considerable length, and those views had been fully set forth in the Minutes of Proceedings. While therefore hoping that there would be a thorough discussion upon the paper, he desired that, as far as possible, it should not be a mere repetition of what had already taken place and had been recorded.

Dr. Percy Frankland asked permission to show the exceedingly simple process that had been devised by Dr. Koch, for determining the number of micro-organisms in water or in any other liquid. He exhibited some of the nutritive material prepared by adding a certain quantity of gelatine to rich beef-tea. It was contained in a test-tube, plugged with cotton-wool, to prevent the ingress of any aerial organisms which would in a day or two cause the gelatine to become putrid and enter into decomposition. So plugged it remained limpid for an unlimited period of time. Before being used the gelatine was melted, which he would do rapidly over a spirit-flame. In practice it was melted at a definite temperature, 30° Centigrade. It had a melting point of about 26° Centigrade, so that it would stand the ordinary indoor temperature experienced in this country in summer. The water intended to be examined by the process was collected in a small bottle which also had been rendered perfectly free from any accidental micro-organisms by heating it in a tin box, care being taken at the time of collection to prevent the entrance of organisms from the hand or from other accidental sources. The gelatine, it would be seen, was now perfectly liquid. The stopper was next removed from the bottle, and a pipette, which had been also rendered free from organic life by heating, was introduced into the water. The cotton-wool was carefully removed, and a certain quantity of the water was introduced into the gelatine in the tube. The wool was then replaced, and the gelatine and water were mixed together. When they were thoroughly mixed they were poured upon a sterilized glass plate which rested upon another perfectly horizontal plate kept cold by means of a dish filled with iced-water placed beneath, and which caused the gelatine poured upon the upper plate to set in the course of a few seconds. The gelatine was poured carefully over the surface of the plate in a rectangular form, and was covered with a bell-jar until the film was solid. When set it was put upon a horizontal stand in

a dish with a glass cover over it to prevent any aerial organisms falling upon the surface of the gelatine. Into the dish was poured a little water to keep the interior in a moist state, otherwise the gelatine dried, and the organisms would not grow on the plate. In two or three days the organisms made their appearance as colonies. He would show them in a magnified form on the screen. These colonies were distinctly visible to the naked eye, and they could be readily seen and counted with the assistance of a microscope of low magnifying power. He would first show what the appearance of the plate was after it had been allowed to develop in the glass dish at a suitable temperature. Each of the large spaces shown on the screen was a colony originating from a single micro-organism introduced into the gelatine. There were different kinds of colonies, some consisting of the large spaces that were scattered about, while others were comparatively small specks, but still readily perceptible. The large colonies were those which caused liquefaction of the gelatine. The little specks on the field were colonies which did not liquefy the gelatine. The next specimen was from some water before filtration through coke, and the next was from the same water after filtration through coke. It would be seen that there were an immense number of organisms in the first specimen, and scarcely any in the second. Another plate would show the effect of agitation with coke, and another the same water after agitation and a certain subsidence. There were, as would be noticed in the first specimen, numerous liquefying organisms besides many of the colonies which did not liquefy; but in the second specimen comparatively few colonies were left. He would also exhibit a few plates with unfiltered river water collected at Hampton, containing a large number of organisms. The next examples were from the ordinary Thames water supply of the various companies in London, which for obvious reasons he would not specify. It would be seen that the number of organisms was enormously diminished, although a considerable number still remained in the field. Another specimen was from the unfiltered water abstracted by the East London Company at Chingford, and another example was filtered water from the Lee, where the diminution in the number of organisms was exceedingly striking. The next specimen represented the average filtered Thames water, which contained very few liquefying organisms, but still many colonies were distributed over the field. A specimen of the Kent Company's water, as would be seen, was remarkably free, only a few colonies remaining.

Mr. C. E. Conder, having given considerable time during the last twelve months to the practical study of the theme brought forward for discussion, wished to express his concurrence in the paper. Many persons might possibly have heard the author speak on the same subject at the Society of Arts two years ago; and they could not but be struck with the gigantic strides that had been made in the interval. He desired to confine himself within the lines laid down by their first President, Mr. Telford, and speak merely of practical investigation in that great field of inquiry. The paper by Mr. G. H. Ogston on the subject of the purification of water by iron, and another recently read by Mr. Winter Blyth, at the Royal Society, together with some discoveries of his own, brought the whole subject into harmony. With regard to the author's fifth conclusion, he hoped that in speaking of biological resurrection he would not lose sight of chemical resurrection. That water might be purified for a time, and then become impure, there could be no doubt. Even with the great purifier, permanganate of potash, he had found that within a week or ten days there was a resurrection of turbid matter in the water, and finally an abominable putrefaction. But the great source of secondary action which interfered with all efforts in the purification of sewage was lime. The Rivers Pollution Commission had spoken of it authoritatively as a clarifier, and not as a purifier; and the secondary action which took place from the use of it was well known. At Hertford, where the sewage was remarkably weak, and where a small dose of lime, under 4 grains to the gallon, was applied, the secondary action took place some miles down the river, at Ware; the water then being of a most offensive nature, as was reported by Major Flower in 1876. The same

secondary action had, he believed, been observed in almost every place where the effect of lime had been carefully watched, and most certainly where it had been mixed with iron. In the only instance of secondary action occurring in his experiments, it was due to the presence of lime and iron. At Bradford, Clifton, and Cheltenham, the same thing had occurred. In one case chloride of iron was used, and in another sulphate of iron. The secondary action was of so foul a nature that the Court of Chancery interfered by injunction, and the works were abandoned. In every case where the two substances—lime and iron—were applied together the same result had happened.

Sir Frederick Bramwell reminded Mr. Conder that the subject of the paper was the purification of water for potable purposes, and not the purification of sewage.

Mr. C. E. Conder said it was exceedingly difficult to draw a line. He did not wish to describe at length any process of his own, unless invited to do so by the Council; but he desired to draw attention to the samples of purified water on the table, which in two cases had been treated in the sewers themselves. There were seven points to be considered in the purification of water and sewage. The first was the destruction of odor and of gas, one of the most fatal causes of disease. The second point was the destruction of micro-organisms in the water, and there was distinct proof that iron was the only substance which absolutely destroyed those organisms. There was not a complete accordance between the experiments of Mr. Blyth and those of Mr. Ogston with sulphate of iron. That might be explained by the fact that Mr. Blyth had used an exceedingly strong solution.

Sir Frederick Bramwell again called Mr. Conder's attention to the fact that the subject under discussion was the purification of water for potable purposes, and not the purification of sewage. Although Mr. Conder had stated that it was often difficult in practice to discriminate between the two, yet in a discussion there was no such difficulty.

Mr. G Bischof thought that the grain of the materials, referred to in the paper as employed in filtration experiments, was too fine for practical purposes, and he believed that all waterworks engineers would bear him out in that opinion. He also considered that the rate of filtration with one or two exceptions was too slow to render the results practically applicable. With regard to the agitation experiments, he endorsed the author's conclusion that the process was unreliable, owing apparently to the numerous conditions which were necessary for its success. Considering the influence of storage on the increase of microphytes, to which he would presently refer, he contended that the samples in these experiments, which had been allowed to settle for half an hour, and for forty-eight hours, could not be compared. The redistribution of organisms referred to by the author was of interest, especially with reference to biological points, but it seemed to be almost in contradiction to the following statement: "During the period of storage, subsidence takes place, the water becoming poorer in suspended particles of all kinds." That would include micro organisms, and he therefore did not quite see how the two statements could be reconciled. Those acquainted with the subject were aware that when water was to be examined microscopically, it was allowed to settle for twenty-four hours, when an accumulation of microphytes would be found at the bottom. The reascension probably took place only when there were currents in the water. With respect to the filtration experiments on London waters, he might mention that he had in one instance succeeded in taking a sample directly the water had left the sand filter, and he there found a reduction of 89 per cent. There was one statement in the paper which he could not pass unchallenged: "Again, in these storage reservoirs a process of starvation may go on, for the organisms present in the impounded water find themselves imprisoned with a limited amount of sustenance, which they rapidly exhaust, and then perish in large numbers, falling to the bottom." He would ask the author to be good enough to reconcile that statement with the following experiment. He filled a number of glass tubes one inch in diameter, which had been sterilized, and drawn out at both ends to a fine point,

to about one-third their capacity with water containing twenty-seven liquefying, and two hundred and ninety total colonies per cubic centimeter. The two points were immediately sealed before the blow-pipe. He kept some of the tubes (in which the organisms were certainly on starvation diet) for forty-four days, and on the last day he found that the twenty-seven liquefying colonies had increased to eighty-three, and the two hundred and ninety total colonies to one thousand seven hundred. That was the result of the starvation. There was one other point to which he felt bound to direct attention. Some time ago he was as enthusiastic as the author himself about the gelatine test. He went to Berlin to see what was going on in Dr. Koch's laboratory, and had tried hundreds of tests, besides making a very large number of experiments, with the object of testing the method itself. He asked himself what was the meaning of those colonies. and why should they be the standard of purity of water? That plain question could be answered in two ways. The colonies might behave in the same way in which chemical poisons behaved. Chemical poisons were harmless in certain quantities, and became injurious or poisonous in others. So the colonies might be harmless in certain numbers, and become poisonous in others. He was convinced, however, that that was not so, at least within a very wide limit, say within a million colonies per cubic centimeter. He would not then give the proof of it, because he could combine that proof with another point to which he would afterwards refer. The only other way that he could see of connecting the colonies with purity was, if they indicated something else which was injurious to health. That something else in his opinion could only be pollution; he therefore asked were those colonies an indication of pollution? In order to answer that question, he might be permitted to refer to the conditions upon which the development of the colonies depended. Perhaps the most important of all those conditions was temperature, because at certain temperatures near the freezing point, the development was entirely stopped, and then it was gradually increased in a most marvelous way, until 30° or 40° Centigrade were reached. The next point was the time allowed for development, or, as it would be called in the case of water, storage. Many of the members were probably aware of the interesting calculations made by one of the foremost bacteriological authorities —Dr. Cohn, of Breslau—some years ago, that a single bacterium would be able to fill up the whole of the ocean with its progeny in less than three days, if only a sufficiency of food, and proper temperature, were given. That brought him to the third condition, food. The fourth condition was aeration, and the last, light. It was evident that of those conditions, temperature, storage, and light had no connection whatever with pollution. Aeration certainly had such a connection, but unfortunately it was of a reverse kind, because it was well known that when there was a deficiency of oxygen, the development of microphytes was checked. Therefore, as the deficiency of oxygen coincided generally with impurity of water, so the impurity of water would actually check, as far as aeration went, the development of microphytes. Thus the only condition remaining was food. This undoubtedly was always the result of pollution, but it should be borne in mind that even in distilled water—which certainly was not polluted, in the common sense of the word, and where there was but a scanty trace of food—enormous numbers of microphytes were sometimes developed. He would go one step further. He had taken a sample of New River water, which would have been called very good in quality by Dr. Koch, if it had contained even twice the number of colonies that he found, namely fifty-three. He had kept the water for six days in a sterilized flask, protected against aerial infection, and then found that instead of one liquefying colony he had six hundred and forty, and instead of the total fifty-three he had seven hundred and seventy thousand colonies per cubic centimeter. If that water could by any possibility be hurtful, it surely would have been known long since from experience, as water was frequently kept on board ship under much more unfavorable conditions and for a much longer period. That was the proof that he had promised, that even water containing such a number of colonies was not necessarily hurtful. He would also

ask this question, if in such water containing so few organisms, and generally so pure, such enormous numbers of microphytes could be developed, was it justifiable to say that no microphytes could be developed unless there were pollution? He hoped that he should not be misunderstood. He was fully convinced of the value of the method, but it should be applied with discrimination. Above all, no attempt should be made to compare totally different waters by the numbers of colonies found. Waters which had precisely the same history might well be compared, but that meant in reality identical waters, or one and the same water, which restricted the applicability of the test. Of course there were a great many laboratory experiments, for which the test was very useful. The author had said that it made a difference when there were different kinds of microphytes, but he could find no allusion whatever to different kinds. The numbers of total colonies only, and not even of the liquefying colonies, were given, and he presumed the author considered that the former were sufficient; otherwise he would have added an explanation to render them sufficient. His opinion, therefore, was that sufficient advance had not yet been made to draw definite conclusions from different kinds of microphytes. The last point to be considered was, whether the search for those specific microphytes, which were the cause of zymotic diseases, such as cholera and typhoid, could be of assistance in drawing conclusions from the test. If the author would be good enough to show him first the bacillus of cholera and of typhoid, he would search for them in samples of water. It was true that Dr. Koch was of opinion that the Comma Bacillus was the cause of cholera, but as long as bacteriologists and pathologists could not agree upon the point, he as a chemist could not be expected to pronounce an opinion upon it. He hoped, therefore, that the author would be good enough to explain thoroughly why he believed that those colonies had any necessary connection with wholesomeness.

Mr. Jabez Hogg remarked that the purification of water in its many-sidedness had been pretty freely thrashed out on former occasions. However, a very important change had taken place. It was now admitted by the analytical chemist that henceforth water purification must rest on a twofold basis—biological and chemical. In the earlier attempts at purification, water-engineers, and he thought he might say all classes of the community, were content if by filtration all visibly suspended matters were removed. If the water after passing through a filter bed had a bright, clear appearance, it was said to be a good and wholesome water. More recent investigations, however, had demonstrated the fallacy of this view, and in point of fact it was now well known that the brightest and clearest looking water might contain a deadly organism—a micro-organism, of course—invisible to the unassisted eye, and undiscoverable by chemical analysis. With the advance of the germ theory of disease the necessity for a test which should recognize the absence or presence of these micro-organisms, became an imperative one, and it was but right to say that the credit of the discovery of a reliable test—the biological—was due to a member of the medical profession, Dr. Koch, of Berlin. This test he had the honor of introducing to the notice of the members of this Institution four years ago, and at the same time he exhibited photographs of the results of his examinations of London water, as well as of Manchester water, which the late Dr. Angus Smith was engaged upon. Since then he was glad to find the author of the paper had been diligently at work with Koch's test, both in his laboratory and "in his periodical examinations of the waters supplied to the metropolis." He now submitted for acceptance the general conclusions to which he had been led by his experimental researches in water purification. Mr. Hogg's remarks would be chiefly confined to the biological part of the question. He thought it would be not only convenient, but absolutely necessary, to get a clear insight into the nature of these exceedingly minute organisms before venturing upon or attempting to deal with the more difficult part of the question, their separation from water, by filtration or other process. It must not be supposed that the micro-organisms in question bore any resemblance to those larger organisms

which infested water, many of which could be seen by the unaided eye, as entomostraca, pulex, &c. No idea either of the excessively minute bodies known as bacteria, microbes, &c., would be gained from the magnified pictures which had been thrown on the screen. It could hardly be imagined that those irregular masses, those colonies, consisted of hundreds of millions of living micro-organisms. To describe them individually, or rather to speak of them collectively, and as a genus, they measured from the $\frac{1}{5,000}$ to the $\frac{1}{50,000}$ of an inch, their movements being regulated by a motor fiber, a flagellum, placed at the extremity of their bodies, and which measured only the $\frac{1}{200,000,000}$ of an inch. Their outer covering or skin was chiefly composed of cellulose, which enabled them to resist the action of strong acids and alkalies, as well as the variations of temperature, cold and heat. As an example of the former he had repeatedly placed them in strong fuming nitric-acid, and at the end of a week or a month had seen them as lively and apparently as unaffected as they were in their natural element. Life was even more persistent in the germs, spores, or ova, than in adults, and it would be an act of rashness to say when every individual of a colony had been entirely destroyed. If the water in which micro-organisms lived was much agitated, or the supply of food fell short, the colony would invest itself with a gelatinous matrix, and sink to the bottom of the water. Germs, or resting spores, would remain quiescent and concealed for a lengthened period of time. Light was an essential for the development of some species; darkness for others. A free supply of oxygen was required by some, others lived and throve without it. But all must have carbon and nitrogen, and these elements they freely obtained from the organic compounds held in solution or suspension in most waters, especially those polluted by sewage. Micro-organisms pervaded air, earth, and water; indeed were so very ubiquitous, that water seemingly free from them at one period of the day might swarm with them later on. There were very many varieties or species of micro-organisms, bacteria, some of which were believed to be harmless, whilst others were known to be poisonous, pathogenic, or incitative of zymotic disease. From this rapid sketch of their natural history it might be inferred that all attempts at sifting them out, or straining them off, from their natural element, water, must be attended with very unusual difficulties—often entire disappointment. To say that this could be done by filtration was, he thought, scarcely warranted by the results already obtained. At all events, the experiments he had made with the view of water-purification had not been attended with much success. He was then unable to accept the general conclusions which the author had arrived at. He did not doubt that filtration would considerably improve water; but any process, were it filtration, precipitation, or what not, and which merely reduced organic life to a minimum, went only a short way towards water-purification. The one or two colonies, or even the one or two individuals, which any process left behind, was a danger which could not be contemplated without producing a shudder. The difficulty must have been present to the author's mind when he said that "the microscopic living particles . . . possess such an astonishing power of rapid multiplication . . . that within a very short period of time it becomes impossible to form an opinion as to the number of original organisms from which the vast population is descended." Just so; and it was therefore the more surprising he should believe it to be "extremely simple to construct filters which shall possess the power of removing micro-organisms, in the first instance at least." Speaking from a not inconsiderable experience, he had not seen or heard of a filter-bed which might be trusted to remove two thirds of the coarser and larger organisms so generally met with in London waters during the summer months of the year. It appeared then almost impossible that a water-logged filter, or even a new filter-bed, should remove 90 per cent. of micro-organisms so infinitely minute, and so much more difficult to deal with. How very much, then, was the author's warning needed to guard against erroneous and hasty conclusions that even the best filters soon lost their power, and consequently must be frequently renewed. There was still, he was convinced, much to learn with regard to filters and filter-

ing materials, and this came out more strikingly on examining them in detail. Take either filtration, precipitation, agitation, or natural agencies, and none of them effected the perfect purification of water. Partial failure was the rule. The spongy-iron process, by way of example, at the Antwerp Waterworks. It was only two or three sessions ago that this was spoken of as a great success. Where was it now? Displaced by "agitation with solid particles." The same fate had been in store for many other processes. He knew of only one exception to the rule—Clark's lime process. This more nearly approached perfection than any other, and possibly its greater success might, in a measure, be due to the excellence of the water in the first instance, for it could not be denied that deep well-water was the best, and least likely to be contaminated, of any of the waters supplied to London. If examined biologically and microscopically soon after precipitation was completed, it would be found free from organisms of all kinds. Indeed, he had submitted it to a further test, that of keeping bottles of the Canterbury water exposed to a strong light, and a uniformly higher temperature in his study, for a whole year; and then, on testing it biologically, he found it free from all micro-organisms. This, then, to his mind, was the water, and the water process of the future. The author further alluded to the difficulty he experienced in the removal of some classes of organisms over others. This was a difficulty experienced by observers. He also appeared to have a preference for the gelatine-peptine solid medium over that of other modes of cultivation. Mr. Hogg found it necessary to employ occasionally less solid media, and for the reason that certain micro-organisms preferred them, and multiplied more rapidly in them. Among solid media he had a preference for the agaragar and peptone sugar culture. He would remind the author that particular species would only propagate in a medium containing less than 10 per cent. of gelatine. Again, septic microbes remained in a quiescent state in the presence of commoner forms, possibly enemies. There were other points of detail and precautions to be observed, which, if neglected, marred the results of experiments, and gave rise to erroneous conclusions. Some error of observation had, he was inclined to think, been the cause of a misunderstanding with regard to Dr. Koch's cholera bacillus. There was a Comma Bacillus, of a somewhat harmless character, often met with in the human mouth, and in other situations. This was a very different organism. Dr. Koch's bacillus had a certain selective preference for one kind of gelatine cultivation over that of another. Dr. Crookshank, who had bestowed a good deal of attention upon micro-organisms, said of Koch's: "No one, so far as I am aware, has yet been able to demonstrate the existence of a curved bacillus which is entirely similar, both morphologically and biologically, to the (cholera) Comma Bacillus of Koch." The author of the paper would, he feared, think him either very fastidious or very difficult to please with regard to water purification. It was so, he must admit; and this arose from the fact that the longer he studied the question the more difficult it became to reconcile differences of opinion which experimental researches almost invariably gave rise to, in the first instance at least.

Mr. S. C. Homersham said that the author had compared the Thames water supplied by different London Companies one with the other, and had stated that the West Middlesex was the first in order of merit. If, however, water was drawn from a main pipe, say in the Strand, it would be found to be in a very different condition, biologically, from that of water collected at the "dead ends" of service-pipes branching from the main down a steeet bounded by the river. Near to these dead ends, when the water was not in motion, organisms lived and bred, and were to be found in swarms. In the mains, where the water was in motion, there were but few, and more especially where there was a comparatively quick current. It was essential, even with the best water, that the dead ends should periodically—at intervals of not more than seven to fourteen days—be blown out. The water at these dead ends would be found somewhat thick and muddy, and containing thousands of animalcules. It was delusive, therefore, to compare the water of different companies unless it

was known exactly where the waters were taken from, the time of the year they were collected, and other conditions. The number and the species (animal and vegetable) of the living organisms varied greatly in different situations and at different seasons.

Mr. W. Anderson (Erith) thought that the paper should be accepted as a useful installment to knowledge on the important question with which it dealt, although he could not himself agree with the conclusions to which the author had arrived, and considered that there were some fatal defects in the arguments he had adduced. In the first place, it had not been proved that the gelatine method of investigation arrested all the microbes, or even the more objectionable ones. In fact, experience rather tended to show the contrary. Last autumn a commission of chemists was appointed by the Hôtel de Ville of Antwerp, to examine into the quality of the water-supply of that city, for the town was crowded with visitors attracted by the Exhibition, and there was a considerable cholera scare caused by the prevalence of the disease in Spain. The result of that examination was a report (a copy of which would be found in the library) in which it was stated that the water was absolutely sterile to Dr. Koch's test. No bacteria of any kind could be found by the cultivation in gelatine, but by cultivation on slices of potato abundant life was discovered. That showed that the method of Dr. Koch was defective, because it did not necessarily embrace all the life that might be found in the water, and that the conclusions derived from it were therefore fallacious. Then it had not been proved that the indiscriminate destruction of bacteria was an advantageous thing. He supposed that it might be taken for granted that the destruction of some species would be an advantage, but it was a great question whether the wholesale destruction of living organisms in impure water would be beneficial. In olden days, when sailing ships made long voyages, the kind of water preferred was the dirty water of the London dock, because it was found that, although, at first, it was extremely offensive, it gradually cleared, and then kept better than any other kind. That was no doubt due to the fact that the living organisms first of all destroyed the organic matter which was in the water, and by that very destruction destroyed themselves and settled down as sediment on the bottom, leaving the water quite clear, and in a condition to keep any length of time. In that case the living organisms were clearly of great benefit, and it had yet to be proved that it was wise to destroy them. Just as small birds preyed upon insects, and so did more good than they did mischief, it was quite conceivable that some harmless species of microbes preyed upon the injurious species, and it was by that means that water which had been contaminated by the germs of zymotic disease gradually cleared itself and became inoffensive again. He also took exception to the tests by which the author sought to determine the relative efficiency of various filtering media. He thought it would be only reasonable, first of all, to ascertain what was the best state of sub-division, the best depth, the best rate of filtration of any particular medium, and then, having ascertained that, to institute a comparison between the media when working at their best. Instead of proceeding in this manner, however, they had all been taken at the same fineness, the same depth, and approximately at the same rate of flow; or, at any rate, if the flow had been varied, it appeared to have been so accidentally. He did not think it was fair to assume that all the substances tried would act equally well under the same circumstances; and in that respect he thought the argument about the relative efficiency of filtering media was erroneous. As far as iron was concerned he could speak with some authority, because he knew by experience that iron passed through a forty-mesh sieve, and arranged in a layer 6 inches deep, would, in three months, be altogether impervious to water. Iron could not be used as a filtering medium in that way. Mr. Jabez Hogg's statement that the process originally adopted at the Antwerp Waterworks was a failure, was altogether incorrect and misleading. Mr. Bischof's system of passing water through a mixture of gravel and iron was perfectly efficient, and continued to be so for more than three years; but, in the meantime, a method was discovered of attaining the same object by agitation with iron; it proved to be more

economical in working, and to require much less space and capital outlay, and was, on those accounts, adopted when the works had to be extended. He also took exception to the author's conclusion III., "That organized matter is to a large extent, and sometimes to a most remarkable extent, removable from water by agitation with suitable solids in a fine state of division, but that such methods of purification are unreliable." He supposed that the author did not intend to include iron in that statement, because, although iron was used by agitation, the effect it produced upon water did not depend upon any mechanical action, but upon a chemical process, and that it was absolutely permanent was proved by the fact that it had been purifying from 1,500,000 to 2,000,000 gallons of water daily, at Antwerp, for more than a year, and, as far as he could see, there had not been the smallest variation in the results. Whether the author's conclusions held good with reference to gravel, brick bats, and similar inert substances, he was not prepared to say—probably it did; but certainly he thought the author ought to make an exception in favor of iron. He did not think that any one process of treatment was competent, of itself, to deal with impure water; but he was certain that, by taking three out of the four systems to which the author had alluded, it was possible to obtain from water, however impure, not only a perfectly safe, agreeable, colorless, potable fluid, but one which, he believed, was much safer than any natural supply, not excluding even that of deep wells. He had repeatedly shown, both from a biological and from a chemical point of view, that by treatment with iron, a process discovered more than thirty years ago by Medlock, and further developed by Mr. Bischof and Sir Frederick Abel, that a chemical change was produced, and the organic impurities were reduced to one third or one-fourth, that the microbes were either destroyed or entangled in the precipitate, and separated by sand-filtration; the color and the bad taste were also destroyed, and water of a thoroughly good quality was produced, not by one process, but by agitation, chemical action, precipitation, and filtration. When that had been done, the water was put into covered reservoirs or mains, which were absolutely free from risk of external contamination; and he considered that such water was better than any natural supply. The process sounded formidable and complicated, but in reality it was merely ordinary sand-filtration with the Revolving Iron Purifier added. The expense of purification was not materially increased, for the cost of the water at Antwerp delivered into the main under 200 feet pressure did not exceed 7d. per 1,000 gallons, interest on capital not included. All rivers or lakes, however pure, were liable to contamination, and deep wells were by no means free from the danger, for there had been numerous instances in which wells, in the neighborhood of London and other places, had been closed in consequence of the contaminations produced by increased population. The process, therefore, which embraced not one only, but several methods of purification, was capable of producing excellent water from sources which had been hitherto considered unsuitable. He might also speak of the universality of its application; because, although the Antwerp Waterworks had been prominently put forward, that was by no means the only case in which the method had been tried. He had employed it with the waters of the Neva and of the Nile, the sluggish rivers of Holland and Belgium, with the waters of the Seine, and even with the effluent of the Hertford sewage works, with thoroughly satisfactory results. Wherever it had been tried, the result had been the same: the reduction of organic matter to one-third or one-fourth, the destruction of color, of the objectionable taste, and a renewal of organic life. He thought that all would agree that the destruction of chemical impurity was a very important feature, because the microbes could not exist without the nitrogenous substances which formed the organic impurity, and which hitherto had been rightly regarded as of very great importance. Therefore any process which would not only destroy the microbes, but which would also destroy the food upon which they existed, must be a valuable one. He took exception to the paper, because it had a tendency to produce an impression, upon those not well acquainted with the subject, that the power of a filtering medium

to destroy living organisms was the great thing to be considered and was the proper test of efficiency. He did not think it was. He believed that all the circumstances connected with a good water supply must be taken into account. The engineer who neglected the color and taste of water would find that if he had to supply a town in which there was spring or well water of agreeable taste, color, and brightness, even though greatly polluted, that a water company would have a very uphill game if it supplied a yellowish, ill-tasting liquid.

Mr. James Mansergh said the subject was one of great interest to engineers, especially to those engaged in the construction of waterworks. It was a very fitting subject for consideration by the Institution, although, as it was a new development, few of the members might be able to enter into a close discussion of its details. He himself certainly was not. They could not afford, however, to ignore the researches of the chemist, the biologist, and the physiologist, and their thanks were due to the author for the graphic manner in which he had brought forward the results of his experiments. He had had the advantage of being a pupil of his father's several years before the author was born. If he might be allowed, without impropriety, to make a purely personal reference, he should like to state that he had a further special interest in the subject, because he had been for some time experimenting, under the advice of an American physician, on a treatment which had involved the taking of a large quantity of undiluted hot water daily. To such an extent had that been the case, that, taking the basis of the figures which had been given as to the number of microphytes found in the filtered water of certain of the London companies, he found that his share during the last eighteen months had been 23,198,400 individuals, possibly colonies —he hardly knew which. He thought it was clear from that experience that the great majority of these organisms were clearly non-pathogenic, that was, inoperative in the production of disease under ordinary conditions. On the other hand, it was equally certain, from the labors of Pasteur, Dr. Koch, and others, that there did exist organisms which undoubtedly possessed truly pathogenic capabilities. For that reason it was of the utmost importance that biological researches should be prosecuted with vigor, especially in the direction of determining which organisms were dangerous, and which were innocuous. In this country scientific men were, he feared, handicapped by the operations of the anti-vivisection acts—backed up in certain quarters by false and mischievous sentiment—and were unable to carry out their researches to the extent permissible on the Continent. This was very unfortunate, because it was absolutely necessary in such inquiries as Pasteur's to make good each step as it was taken by actual experiment upon some of the lower forms of animal life. He would ask the author, in his reply, to give a little further explanation of the blister like appearance of several of the plates. He had to some extent explained it by saying that certain of the organisms had the power of liquefying the gelatine, but he thought that that might lead to considerable errors in the counting of the numbers. Surely those great blebs must spread over and obliterate many of the small compact colonies which were shown on the diagrams. He would also ask for the author's opinion upon the discoveries of Mr. R. Warington. Mr. Warington had found that there were certain bacteria which effected the nitrification of other organic matter, and that these creatures had their habitat in the upper surface of the soils of manured lands. Those experiments were carried out on the model farm at Rothamsted under Messrs. Lawes and Gilbert. Mr. Warington appeared to have satisfied himself that the nitrification was due principally, if not entirely, to these microbes. If these conclusions were correct, it would appear that the author's suggestion, to drain the beds of the intermittent filtration process for the purification of sewage which he had invented, 6 feet deep, might be materially modified. Impressed with this idea, he had some months ago discussed the matter with Dr. Frankland, and had subsequently advised the preparation of four burnt clay filtration areas on a sewage farm near London, side by side, and of exactly similar size and formation, excepting that the depths were respectively 2 feet, 3 feet 3 inches, 4 feet 6 inches, and 6 feet. These were now being experimented with, and the results

would be interesting as proving or disproving that the shallow beds were as efficient as the deeper.* He was also considering the advisability of importing soil from a farm where the nitrification went on satisfactorily, and sowing it, with its contained bacteria, upon another apparently deficient in those organisms, so as to inoculate the latter into efficiency. Coming back directly to the subject of the paper, it appears to be clear that the microbes in the case of the sewage farm were performing an exceedingly useful function; and he should like to ask the author if it might not be that the majority of the organisms found in potable waters were operating in a similarly beneficent manner.

Mr. E. K. Burstal remarked that the paper was of a purely chemical nature, and that it was somewhat difficult for engineers to grasp its details fully. The tables certainly showed the wonderful effect produced upon water by mere sand-filtration. Only 2 or 3 per cent. of the microphytes remained, but it was not evident whether it was the dangerous ones that had been removed. The healthy condition of London would seem to indicate that that was the case. He certainly took exception to the way in which the "order of merit" had been obtained. In the table at page 326 there were six columns. In the the third column the average storage in days began at 14.7, and therefore the Chelsea Company, having that figure, were credited with the first place. The numbers 1, 2, 3, 4, 5, etc., were purely arbitrary, and ought to be accepted with great caution. The rate of filtration per square foot was the same. Regarding the thickness of sand, there was nothing to show that 4 feet 6 inches were better than 3 feet 3 inches. As to the average number of micro-organisms found in the water, the number for West Middlesex was six, and for Chelsea fifteen, but the author stated that the number in water from a deep well in chalk at Sudbury was twenty-five. After all that had been stated by the author's father and himself, and all the attacks that had been made upon London water, did he mean to imply that sand-filtration rendered the water better and more potable than that obtained from the chalk? If that was the case the new method of examining water would lead to a thorough revolution in the views generally held on the subject. He did not think that a stronger argument in favor of the quality of the water at present supplied to London could be found than that contained in the paper, if the facts stated were correct. Mr. Anderson, however, appeared to think that the gelatine process ought not to be accepted in all respects as a satisfactory one. It would be interesting to know what were the views of chemists on the subject. As he before stated, he could not agree with the order of merit given by the author in regard to the quality of the waters.

Mr. W. W. Beaumont said that although some of the criticisms on the paper had been adverse to the use of the system described, there had not been for a long time before the Institution a paper that was so flattering to engineers in the results which it related. The figures in the paper showed that the Thames water, notwithstanding the character often attributed to it, might be as good as that which was most praised by chemists. The system described had been, it was said, brought to perfection by one who had more laboratory room and materials at his disposal than could be found in the whole of England, and it might therefore be assumed that the figures might be taken as of as much value to engineers as anything the system with its numerous sources of vitiation could give, in enabling an opinion to be formed as to the results of engineers' work. It appeared from the tables that the Kent well-water as supplied contained many more micro-organisms than the Thames water, supplied by the West Middlesex Company. The water from the Kent wells at Deptford contained from six to eight micro-organisms, but as supplied it contained as many as twenty six. If the water from the well to the supply could so gain in pollution it was somewhat remarkable that there was so small a growth of organisms in the water supplied by the river companies, because it must be assumed that the water was purer, as far

* It was a curious coincidence that on the 14th of April, the day after the above remarks were made, a letter appeared in *The Times*, written by Dr E. Frankland from Castellamare, referring to a report on the mode of treatment intended to be adopted by the Metropolitan Board of Works for the London sewage, and stating that whereas in the Rivers Pollution Report he had recommended 6 feet depth of earth for intermittent filtration, he now had reason to believe that 2 feet would be equally effective.

as the organisms were concerned, in proportion to the numbers in the water as it left the filters in the one case and the wells in the other. That did not, however, seem to be the case, for, taking some of the other figures, in the Grand Junction and Chelsea Works the numbers remained very low, and the author had pointed out that those numbers bore some direct relation to the thickness of the filters or of the sand-beds—in other words, to the amount of mechanical action to which the water was subjected. The paper was gratifying to engineers, because it showed that they had for a long time been able to do, with the means at their disposal, as much as chemists and biologists could now teach them to do by their most recent researches, aided by the most complete apparatus. The author, in describing his process, stated that in taking the gelatine from the bottle it was necessary to be very quick in putting it under the glass vessel. If, however, the result of a test could be vitiated by so short an exposure, it was not surprising that the Kent water was found to rise suddenly in impurity from six or eight organisms to twenty-six, as between the well and the company's pipes. That proved that, although the water supplied by the river companies was so good, it would be even better if it could be a constant supply. If the water could be rendered so rapidly impure as the author's remarks appeared to indicate, London people must, as a rule, be drinking water from the ordinary house cisterns that was vitiated largely by organisms.

Mr. W. Morris (Deptford) said he thought the paper most interesting to engineers, as it showed what filter-beds were really doing. He believed that some of the organisms referred to would be found in the waters of all lakes and rivers. After passing through filter-beds there was, as the author had shown, a very great reduction in the number of the organisms, but it would appear that those which remained in the filtered water increased so rapidly that if the water were kept long enough it would be found to contain its original proportion of colonies. If the organisms contained in good potable waters had no influence on health, their number would be of little importance; but, as had been urged by chemists and other scientists, such water might be accidentally contaminated by disease germs or pathogenic organisms derived from excrement or other sources, and to provide against such a contingency it became important to remove the whole of the organisms by filtration, although only a very small percentage might be really injurious. If the present system of filtration had in some cases removed 98.9 per cent. of the organisms, was there not reason to believe that by improved filters even better results might be obtained? The results given by Mr. Anderson of agitation with iron, pointed to another valuable means of purifying water in connection with filtration. The depth of the sand used in filter-beds had been alluded to, but the quality of the sand was also a matter of some importance. There might be a great depth of sand, but if it were not sufficiently fine the result would not be so good as with a smaller depth of a finer and better material. From his experience of the filter-beds formerly in use at the Kent Waterworks, he believed that the deposit of suspended matter, and the growth of vegetation on the surface of the sand, materially assisted in the filtration of the water; as it had to pass through the interstices of much finer strainers than the sand itself. In Berlin it was reported that covered filter-beds were not so efficient in removing these organisms as those which were open and uncovered; the reason for this might be that the covering of the filter-beds checked the growth of the vegetation on the surface of the sand, which would have assisted in the removal of the organisms.

Mr. C. W. Folkard thought that one or two of the speakers had hardly been fair in their criticisms, because the first thing a scientific man ought to do was to follow the truth, and if it was necessary, in some little way, to go back from his opinion, that ought to be done. Four years ago he had read a paper on a somewhat similar subject before the Institution, and he thought that since that time very great strides had been made in the examination of water. He was then strongly of opinion, as he believed most people were, that there was no method by which to determine whether water was wholesome or not. Of course Dr. Koch's method was not perfect, but he thought

chemists were now on the road to a process which would show whether water was really wholesome as distinguished from being chemically pure. As a pupil of the late Dr. Medlock, he thanked Mr. Anderson for pointing out that to the former was due the credit of first drawing attention to the great power of iron in purifying water.

Mr. C. Ekin remarked that one point in the discussion had not been sufficiently elucidated. Mr. Anderson, in alluding to the fermenting process that took place in the case of Thames water taken on board ship in the olden times, and its subsequent wholesomeness, hinted at the possibility of micro-organisms in water being somewhat beneficial in their operation. As a matter of fact, he believed that they were among their best benefactors, for what Mr. Anderson had supposed might take place had actually been proved to do so. In a discussion at the Chemical Society a few weeks ago Dr. Klein, who was an authority perhaps hardly second to Dr. Koch, assured the meeting that the septic organisms were absolutely inimical to the pathogenic organisms that accompanied disease, and not only were they inimical, but they were so much stronger, and their vitality so much greater, that it was not possible for the disease organisms to exist in their presence. With the caution and diffidence of the true man of science, Dr. Klein confessed that there was much that was hazy in the present knowledge of these organisms, and he especially warned chemists against drawing deductions from very incomplete data. The fact of the one set of organisms destroying the other was, however, clear, and its practical importance could hardly be overrated. It explained, too, what had hitherto been a mystery. Many present must have often marveled at the fairly good health of communities drinking waters even grossly polluted. The Thames received quite sufficient pollution, but it was purity itself as compared with several of the rivers supplying some of the northern towns. Now these rivers received the dejecta of thousands of pa ients suffering from typhoid fever, and it was a wonder what possible agency could be at work to prevent the wholesale decimation of the populations subject to these influences. Wherever pollution existed, bacteria swarmed, apparently in some direct ratio to the extent of the pollution. If their presence was fatal to the existence of the organisms accompanying disease, and Mr. Ekin had spoken and written of them for years as playing the part of useful scavengers, then instead of holding them up to opprobrium, they ought to be looked upon as real benefactors. It must not be supposed, however, that he advocated swallowing the scavenger, or that he undervalued efficient filtration. He only wished to caution the meeting against sensational deductions from the presence of the few bacteria that might be found in filtered river waters.

Mr. J. A. Wanklyn said that the subject of the paper was one in which he had been interested for nearly twenty years, and he believed that his views were pretty well known through the medium of his book. His belief was that there was one safe and rational way in which to regard organic matter in drinking water, and that was to assume that it was highly dangerous, and to classify waters according to the proportion of organic matter present. He attached very little importance to searching after organisms in drinking water; indeed, he looked upon such investigations with a great deal of contempt. Eighteen years ago, before the Royal Commission, presided over by the Duke of Richmond, he ventured to say that the London water was cleaner and more wholesome than the water of Loch Katrine. He was laughed at at the time, but now even Dr. Frankland, who at that time talked of mountain air and mountain water, had come to admit that there was more organic matter in Loch Katrine than in certain London waters. With regard to the question of filtration, he held that organic matter could be removed from water with the greatest ease by filtration through many media.

Mr. S. C. Homersham observed that the statements which had been made with regard to taking in water from the Thames for vessels in the docks near London, that it fermented on the voyage, and afterwards became clear and good, were entirely erroneous. He had, many years ago, closely investigated the matter, and was therefore able to speak with confidence on the subject. Mr. Martin, the Engineer to the West India Docks Company, had informed him that many years since the company went to the

trouble and expense of putting up filter-beds to filter the water obtained for this purpose from the Thames; that it was, however, found to become so bad on the voyage that the company gave up using it, and resorted to other water. This had been the case for many years past. Many vessels now obtained supplies of uncontaminated spring-water derived from the chalk at Erith, Gravesend, and other suitable places alongside the Thames.

Dr. Percy Frankland, in reply, said he had been asked to explain more fully than he had already done some of the details of the process of gelatine culture. In the first place the gelatine and peptone mixture did not develop organisms of itself, but they had to be imported into it either from the air or from the water or from some other external source; and then the question had been asked how it was possible to separate the organisms introduced from the water from those introduced from the air during the manipulations which the process entailed. Into the first of those questions it was hardly necessary to enter. Of course it involved the well-known question of the spontaneous generation of life. It had long been fully established that if the media which were capable of nourishing those lower forms of life were sterile, and were then preserved from the access of such low forms of life or their germs, they would remain unchanged for an indefinite period of time. Every pot of jam and tin of meat was an illustration of that principle. The jam or meat was sterilized, and as long as the pot which contained it was not open it remained unchanged; but as soon as aerial organisms gained access various putrefactive and other changes would in time take place. The introduction of organisms from the air probably required more explanation. It was no doubt observed that, in his manipulation, the greatest care was taken that the exposure of the plate to the air should be as short as possible; but even with such exposure there was, at any rate, a risk, especially in a room where there was a good deal of dust, of considerable contamination taking place. In all cases when plates of that kind were put up for examining waters or other liquids, he made a practice of putting up at the same time a plate to which no water had been added, but which had experienced the same exposure to the air as the water plate. Then if the plate showed any serious aerial contamination, he should expect to find the same in the water-plate, and the experiment would be rejected. To show that under ordinary circumstances that was not the case, he had brought with him a few plates to exhibit to the members. There was an air-plate containing absolutely no organism upon it, and there were two plates with the cultivation of a comma bacillus. If the air had not been as pure as it was on the occasion when the plate was put up, two or three organisms might be found; but in comparison with the ordinary plates that slight experimental error was of very little moment. These aerial organisms could generally be readily distinguished from the organisms derived from the water, because they rested absolutely on the surface, and they were generally moulds, while the organisms found in the water were very rarely moulds. He much regretted that several of the speakers, and notably Mr. Bischof, had imported much into the discussion which had really no relevance to the matter contained in the paper. Mr. Bischof had started with the assumption, and many other speakers had done the same, that he had endeavored to make out a case for the existence of a connection between the abundance of micro-organisms in water and its wholesomeness. That assumption had been made without reference to any particular passage in the paper, and he thought that Mr. Bischof and the other speakers would find some difficulty in pointing out any passage either in this paper, or in any of his previous publications on the subject, in which such a connection was said to exist. He thought that Mr. Bischof had confounded his own previous attitude of mind with Dr. Frankland's, and it was really against himself and his own utterances that his attack should have been directed. From the first, Dr. Frankland's idea had been to apply the gelatine process to an investigation of the much-vexed question of the value of processes of water-purification, which had hitherto rested upon an altogether speculative basis. It was with that view that the experiments he had brought before the Institution were undertaken; it had been with that view that

month by month the London waters had been submitted to examination by that test, and a little consideration would at once render it apparent that that investigation could be carried out without any reference to the influence of those micro-organisms upon health, the problem being simply to ascertain whether and to what extent various processes of purification had the power of removing micro-organisms in general; but the results obtained in such an investigation, made as it had been with the motley assemblage of organisms found in unfiltered river water, in soil extract, or in sewage, obviously had a wider significance, inasmuch as those processes of purification, which were capable of removing such a heterogeneous crowd of microbes, might be safely assumed to be able to deal with any other kind of micro organisms whatever, whether harmless or pathogenic, because neither in their size, nor in their form, nor in their habits could pathogenic organisms be sharply distinguished from non-pathogenic. Thus, in the matter of filtration, there was absolutely no reason to suppose that a pathogenic organism behaved differently from a non-pathogenic organism. He emphatically stated, and he challenged contradiction, that he had never gone beyond that in his conclusions. He had never asserted that water containing a smaller number of micro-organisms was *ipso facto* more pure or wholesome than another water containing more. His paper treated of the removal of micro-organisms in water, and not of the wholesomeness or unwholesomeness of such organisms in general. On the point of removing micro-organisms from water, of which so much used to be said by Mr. Bischof before any satisfactory means of determining such removal was in existence, Mr. Bischof was now ominously silent. In that lay doubtless a key to his acknowledged loss of enthusiasm for the process. He had listened with much interest to the remarks of Mr. Jabez Hogg, concerning the behavior of the organisms; but he was not prepared to endorse the statement that micro-organisms might be preserved in fuming nitric-acid without suffering any discomfort. He had not the slightest doubt that when the micro-organisms were placed under the microscope, they still showed movement; but he ventured to say that if they had been submitted to cultivation in gelatine, or some other nutritive medium, it would have been found that their vitality was lost. Those minute organisms, in common with other minute particles, exhibited a peculiar kind of motion which had nothing to do with vitality. A number of similar experiments, showing the extraordinary powers of resistance which micro-organisms were supposed to possess, had been placed before the Chemical Society some years ago by the late Mr. J. Hatton, who applied no further test to the organisms beyond looking at them under the microscope and seeing them move about. Those tests were of course made before the test of gelatine cultivation, though not before the ordinary broth cultivation, and he thought it was high time that the fallacy of that mode of recognizing the vitality of micro-organisms should be pointed out. Mr. Homersham had stated that it was impossible to compare the various water supplies, inasmuch as the samples might be taken from the dead ends of service pipes branching from the main. All the samples to which he had referred had been taken from places which were expressly recommended by the engineers of each individual company, and he need hardly say that he did not think these gentlemen would recommend the taking of samples from such manifestly unsuitable and disadvantageous places. Of course, if samples were taken from such places the results would be very different. With regard to Mr. Anderson's criticism of the gelatine process in general, and the illustration which he gave of its alleged weakness by referring to the results obtained in Antwerp, he could only say that he could not be responsible for other people's gelatine. He had no doubt that some gelatine, improperly prepared, might not develop organisms at all. Much depended upon how the gelatine was made. He knew the quality of the gelatine which he himself made, but could not be prepared to guarantee the results obtained from gelatine made by anybody else. The mixture to which he had referred was used by Dr. Klein in this country, and by nearly every bacteriologist engaged in the cultivation of micro-organisms It was quite true that the gelatine-pep-

tone medium was not suitable for the cultivation of all micro-organisms, but it was well adapted for the vast majority of known forms. With reference to the criticism as to the rates of filtration at which the various substances had been tested, of course to make the inquiry absolutely complete every conceivable rate should be tried for every individual substance. He thought, however, that the first way of attacking the question was to use the same depth of each substance, and to make the rate as nearly constant as possible, and even that was a matter of great difficulty. One point had been brought forward by Mr. Anderson which he most emphatically challenged—that it was of the greatest consequence to purify water chemically, because, if it was so purified, the organisms, notably the pathogenic organisms, could not exist in it. That was likely to give rise to serious misunderstanding. Although he did not agree with Mr. Jabez Hogg that these organisms were capable of enduring strong nitric-acid, yet he was strongly of opinion, and he knew it as the result of experiment, that pathogenic organisms could be kept for a long period of time alive in pure distilled water. He did not believe that purification by agitation with iron, or by filtration through particles of iron, would render water as pure as distilled water, and he did not think that water which was chemically pure could be considered safe on the ground of micro-organisms if afterwards introduced would not live in it. It had been stated that Dr. Klein had remarked that septic organisms were absolutely fatal to pathogenic organisms; but he certainly did not make such a sweeping statement. He said that there were some experiments which seemed to show that some pathogenic organisms were destroyed by septic organisms. That that took place with the extraordinary rapidity implied by Mr. Ekin's observation was certainly not the case. If some pathogenic organisms were placed in a given medium with septic organisms, and they were allowed to enter into competition, in all probability in the course of time the pathogenic organisms would have disappeared, and the septic organisms would have gained the mastery, but there was no evidence that all pathogenic organisms would behave in that way; and in the present incomplete state of knowledge it was highly undesirable to place any reliance on such fragmentary observations.

Sir Frederick Bramwell, President, said he feared that as a practical body the meeting could not help feeling troubled at the want of result attendant on the paper and its discussion. He thought it was not too much to say that it had been left an open question as to whether the organisms did any harm, whether if some were harmful others were not innocent, whether there were not some organisms which destroyed others, and whether it would not be well to leave the destroyers in the water so that they might destroy. Nobody knew which were the bad and which were the good, or whether the bad would eat up the good, or the good eat up the bad. He would ask anyone (except perhaps Mr. Mansergh, who had swallowed twenty-three millions of organisms without feeling any the worse for it), whether on going home he would be prepared to drink a glass of water, even if treated with strong nitric-acid. He felt in the most complete state of confusion, and more inclined than ever to adhere to the practice of never drinking water unless it had been boiled. Seriously, the paper and the discussion were enough to cause great alarm by showing the danger of drinking polluted water; but having excited this alarm he could not find that any remedy was agreed on by which that alarm might be satisfactorily allayed.

The total length of the Austro-Hungarian railways in 1885 was 21,980 kilos., against 20,818 in 1884, showing an increase of 1,162 kilos., equal to 5.6 per cent. During the same period the traffic had decreased to the extent of 4.8 per cent. for passengers, 1 per cent. for goods, and the return per kilo. had fallen off by 5 per cent. The gross receipts show an increase of only 0.3 per cent., those for passengers and luggage an advance of 2.7 per cent., whereas the goods traffic declined 0.4 per cent. The reduced rates for goods traffic introduced on many lines was accompanied by a simultaneous decline of the traffic in merchandise and other goods, and both circumstances naturally contributed to a reduction of the gross receipts. The average receipts per kilo. were less than in 1884, a year already distinguished by low average returns. They amounted to 12.223 florins in 1882, 12,268 florins in 1883, 11,718 florins in 1884, and to only 11.135 florins in 1885, and have, consequently, fallen off by nearly 9 per cent. since 1882.

HYPSOMETRY.

By IRA O. BAKER, C. E., Professor of Civil Engineering, University of Illinois.

Contributed to Van Nostrand's Engineering Magazine.

I.

§ 1. Hypsometry is that branch of geodesy which treats of the measurement of heights, either absolute when referred to the sea level, or relative between any two points on the earth's surface. There are three principal and independent methods in use.

The first depends upon the law of the decrease of pressure of the atmosphere with an increase of altitude; this method employs the barometer, and may be called barometric leveling. The second depends upon the measurement of the vertical angle and the horizontal distance. It employs an angle instrument, the horizontal distance usually being given by triangulation; the elevation is then determined from the known parts of a triangle, hence the name trigonometric leveling. The third consists in measuring the distance of two points above or below a horizontal line; this is ordinary leveling, in which a leveling instrument gives a visual horizontal line. Notice that the second is the only one applicable when one or both stations is inaccessible. These three methods will be treated separately in succeeding chapters.

§ 2. In a geodesic survey conducted to determine the size and figure of the earth, the vertical element is required, although it is not nearly as important as the horizontal. For example, the profile of the base must be determined so that the measurement may be reduced to a level line, and its elevation above the sea level must be known, that the measurement may be reduced to the level of the sea; in planning the triangulation, at least the approximate difference of level of the vertices of the triangles is required to determine the height to which the signals must be elevated that they may be visible from the other stations.

When the object of the survey is a map, the vertical element is more important; if the map is to serve as a basis of a geological or topographical survey, the vertical element is equally as important as the horizontal element, or perhaps more so. If the map is to be useful in the preliminary examination for railroads, canals, river improvements, etc., the vertical element becomes the most important.

§ 3. Of the three co-ordinates necessary to completely determine a point—1, vertical distance; 2, horizontal distance, and 3, direction—there is the greatest uncertainty in the results for the vertical distance. It is only very recently that leveling has been done with an accuracy that would compare favorably with other geodesic operations. This is partly due to the fact that early geodesic operations were carried on for scientific objects which did not involve the vertical element, and partly to the natural difficulties, which will be discussed presently.

Chapter I.

LEVELING WITH MERCURIAL BAROMETER.

§ 4. *Barometric Leveling in General.*—The difference in height of two places may be determined by finding the difference of their depths below the top of the atmosphere. The height of the atmosphere above any point is determined by weighing it; this is done by trying how high a column of mercury or other liquid the column of air above it will balance, or by finding the pressure it will exert against an elastic box containing a vacuum, or by observing the temperature at which a liquid boils, *i. e.*, by observing the temperature at which the pressure of the atmosphere just balances the tension of the vapor. This gives rise to three slightly different methods, according to whether the instrument is a mercurial barometer, an aneroid, or a thermo-barometer or boiling point apparatus.

Barometric leveling is specially adapted to finding the difference of level between points at considerable horizontal or vertical distance apart. Under these conditions it is the most speedy, but the

least accurate of any of the methods of leveling. It is very valuable in making geographical surveys of large areas for determining the elevation of stations to be occupied by the topographer. It is also well suited to making a reconnoissance for a railroad, or for a scheme of triangulation.

Sec. 1. The Instrument.

§ 5. *Description.*—There are two kinds of mecurial barometers, the cistern and the syphon; the former is the best and most reliable for hypsometrical purposes. The general form of the cistern barometer needs no description; Fig. 1 shows the cistern and details at the lower end

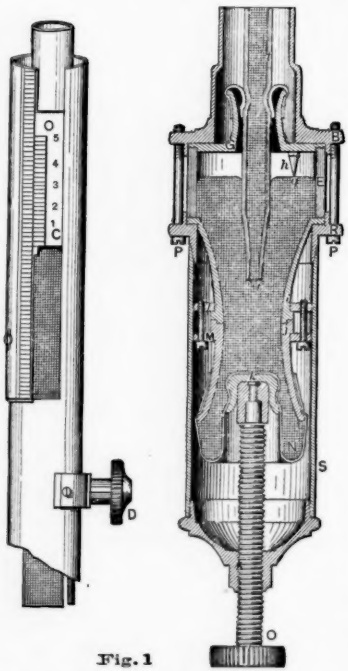


Fig. 1

of the instrument. "The cistern made up of a glass cylinder F, which allows the surface of the mercury to be seen, and a top plate G, through the neck of which the barometer tube *t* passes, and to which it is fastened by a piece of kid leather, making a strong but flexible joint. To this plate, also, is attached a small ivory point *h*, the extremity of which marks the commencement or zero of the scale above. The lower part, containing the mercury, in which the end of the barometer tube *t* is plunged, is formed of two parts *i j*, held together by four screws and two divided rings *l m*. To the lower piece *j* is fastened the flexible bag N. made of kid leather, furnished in the middle with a socket *k*, which rests on the end of the adjusting screw O. These parts, with the glass cylinder F, are clamped to the flange B by means of four large screws P and the ring R; on the ring R screws the cap S, which covers the lower parts of the cistern, and supports at the end of the adjusting screw O. G, *i*, *j*, and *k*, are of boxwood; the other parts of brass or German silver. The screw O serves to adjust the mercury to the ivory point, and also, by raising the bag, so as to completely fill the cistern and tube with mercury, to put the instrument in condition for transportation."*

§ 6. *Filling the Barometer.*—It is no slight matter to properly fill a barometer. It can best be done by the manufacturer, who has all the facilities; but as it is sometimes necessary for the observer to refill it, the following hints are given. Tubes require refilling owing to the breaking of the glass or to the entrance of a bubble of air.

The mercury should be chemically pure and free from oxide; otherwise it will adhere to the glass and tarnish. Moreover, if it is not pure, the height of the barometric column will not be correct; only mercury should be used which has been purified by distillation. For the best results, the mercury should be boiled in the tube to expel moisture and air; but this cannot always be done, and fair results can be obtained without boiling. The following description of the method of filling is from Smithsonian Report, 1859, page 440, and is recommended by Williamson (p 140).

"The glass tube, which should be clean and dry, must have its open end ground straight and smooth, so that it can be closed air-tight with the finger, which should be covered with a piece of chamois or kid skin. Warm well both mercury and glass tube, and filter in through a clean paper funnel with a very small hole (about $\frac{1}{10}$ of an inch) below,

* Smithsonian Mis. Col., Vol. I.

to within one-fourth of an inch of the top. Shut up the end and turn the tube horizontal, when the mercury will form a bubble that can be made to run from end to end by change of inclination, which will gather all the small air bubbles visible that adhered to the inside of the glass tube during filling. Now let that bubble, which has grown somewhat larger, pass to the open end. Fill up this time with mercury entirely, and shut tightly. Then reverse the tube over a basin, when, by slightly relieving the pressure against the end, the weight of the column of mercury will force some out, forming a vacuum above, which ought not to exceed one-half an inch. Closing up again tightly, let this vacuum bubble traverse the length of the tube on the several sides, when it will absorb those minute portions of air, now greatly expanded from removed atmospheric pressure, that were not drawn at the first gathering. The perfect freedom from air is easily recognized by the sharp concussions with which the column beats against the sealed end, when, with a large vacuum bubble, the horizontally held tube is slightly moved."

"A barometer so prepared will probably read lower by a few thousandths than if the tube had been boiled, but in a stationary barometer its error will probably not soon change, and carrying on horseback will be apt to improve it rather than otherwise, as it is then carried with the cistern uppermost, and the bubbles will be jolted toward the open end."* If possible it should be compared with a standard barometer.

§ 7. "To fill a tube by boiling, an alcohol lamp is needed, although it can be done over a charcoal fire. The lamp being filled and put in order, begin to fill the tube by pouring in through the funnel as much warm mercury as will occupy about five inches; then, holding the tube with both hands above the mercury, heat it gently, and let it boil from the surface of the mercury downward to the end of the tube, and then back again, chasing all of the bubbles of air upward. A little practice will make this easy, the tube being held a little inclined from the horizontal, and constantly and rapidly revolved, always in the same direction, so that every portion of the metal may be heated gradually and uniformly. After this has been done, let the tube cool sufficiently to admit of its being held by the gloved hand, and then pour in enough warm mercury to occupy several inches more of the tube, which may now be held with both hands, one above and the other below the heated portion. After boiling this thoroughly free from air, repeat the same operation with more mercury added, until the tube is filled to the end. With care and practice the mercury may be boiled entirely free from air up to within an inch or less of the end of the tube. A tube filled in this way may have, in every respect, as perfect a vacuum as one prepared by a professional instrument maker."†

§ 8 In extended barometric operations in the field, a supply of extra tubes is carried, to be used in case a tube is broken. These tubes should be drawn out so as to be a little longer than they are required to be when fitted into the barometer. The open end should be cut off to such a length that it shall always be immersed and yet not interfere with the rise of the lower part of the cistern. When the instrument is finally put together, the cork in the upper end of the brass case should be adjusted so as to hold the closed end of the tube firmly.†

§ 9. *Cleaning the Barometer.*—It frequently happens that the mercury in the cistern becomes so dirty that the ivory point, or its reflection in the mercury, can no longer be seen; this often occurs even though the barometer be in good condition in every other respect. The instrument can be taken apart and cleaned with safety and without changing in the slighest degree the zero of the instrument.‡ Everything used in the operation must be clean and dry. Avoid blowing upon any of the parts, as the moisture from the breath is injurious.

"Screw up the adjusting screw at the bottom until the mercury entirely fills the tube, carefully invert, place the instrument firmly in an upright position, unscrew and take off the brass casing which encloses the wooden and leather parts of the cistern. Remove the screws, and lift off the upper wooden piece to which the bag is attached; the mercury

* Williamson on the Barometer, p. 140.
† Williamson, p. 138. ‡ Williamson, p. 136.

will then be exposed. By then inclining the instrument a little, a portion of the mercury in the cistern may be poured out into a clean vessel at hand to receive it, when the end of the tube will be exposed. This is to be closed by the gloved hand, when the instrument can be inverted, the cistern emptied, and the tube brought again to the upright position. Great care must be taken not to permit any mercury to pass out of the tube. The long screws which fasten the glass portion of the cistern to the other parts can then be taken off, the various parts wiped with a clean cloth or handkerchief, and restored to their former position."

"If the old mercury is merely dusty, or dimmed by the oxide, the cleaning may be effected by straining it through chamois leather, or through a funnel with a capillary hole at the end, of a size to admit of the passage of but a small thread of the metal. Such a funnel is conveniently made of letter paper. The dust will adhere to the skin or paper and the filtered mercury will present a clean and bright appearance. If chemically impure, it should be rejected, and fresh, clean mercury used. With such clean mercury the cistern should be filled as nearly full as possible, the wooden portions put together and securely fastened by the screws and clamps, the brass casing screwed on, and the screw at its end screwed up. The instrument can then be inverted, hung up, and readjusted. The tube and its contents having been undisturbed, the instrument should read the same as before."*

With the instrument before the operator, these instructions are easily understood. If a little mercury has been lost during the operation, and there is none at hand to replace it, no serious harm has been done; but if much is lost, the open end of the tube may become exposed in inverting the instrument, in which case air may enter. In this case, as in using and caring for any instrument, a little care and a thoughtful inspection of the method of construction is worth more than any written description.

§ 10. *Transporting the Barometer.*—"In transporting a barometer, even across a room, it should be screwed up, and carried with its cistern uppermost. For traveling, it should be provided with a wooden and leather case. In steamboats or railroads it should be hung up by a hook in the stateroom or car. In wheeled vehicles it should be carried by hand, supported by a strap over the shoulder, or held upright between the legs; but it should not be allowed to rest on the floor of the carriage, for a sudden jolt might break the tube. If carried on horseback it should be strapped over the shoulder of the rider, where it is not likely to be injured, unless the animal is subject to a sudden change of gait. When about to be used it should be taken from its case, while screwed up, gently inverted and hung up, when it can be unscrewed. While it has its cistern uppermost the tube is full, is one solid mass of metal and glass, and not easily injured; but when hung up, a sudden jolt might send a bubble of air into the vacuum at the upper end of the tube, and the instrument would be useless until repaired."*

§ 11. *Reading the Barometer.*—Read the attached thermometer first; it is more sensitive than the barometer, and the heat of the body affects it, while the barometer is not affected. The thermometer should be read as closely as possible, for a difference of 0.1°F is equivalent to about 3 feet in altitude; parallax should be carefully avoided in reading the thermometer.

Then bring, by means of the adjusting screw at the lower end of the instrument, the ivory point just touching the mercury in the cistern. If there is a line of light visible between the point and mercury, the instrument is set too low; if neither a line of light nor a depression can be seen, the adjustment has been correctly made. When the mercury is bright, a shadow of the point can be seen, and if the shadow and the point itself form a continuous unbroken line, there can be no line of light. It is usually best to lower the screw till a distinct line of light can be seen, and then gradually raise it until the light disappears. Before making the final adjustment, tap the barometer a little just above the cistern, to destroy the adhesion of the metal to the glass. Complete the contact of the mer-

* Williamson, p. 137.

* Williamson, p. 134.

cury and the ivory point, at the same time being certain that the barometer hangs freely, *i. e.*, vertically.

Next, tap the barometer gently in the neighborhood of the top of the mercury column to destroy the adhesion of the mercury; this is very important, since raising or lowering the mercury in the previous operation materially affects the form of the upper surface. Then take hold lightly of the brass casing of the barometer, not near the attached thermometer, so as not to unnecessarily heat either the case or the thermometer, and by means of the mill-head screw near the middle of the tube, bring the front and back edge of the vernier into the same horizontal plane with the top of the mercury in the tube, just touching it and no more, and then remove the hand. Move the eye about, and if, in any position, a line of light can be seen between the mercury and the vernier, the latter must be moved down a little; if there is no line of light, but a large space is obscured, the venier must be moved up a little. As the top of the column is more or less convex, when the adjustment is correctly made a small place is obscured in the center, when the light is seen on either side.

Finally having adjusted the instrument as above, it may be read at leisure. On the best barometers the scale is usually divided to inches, tenths, and half-tenths; the vernier reads to one twenty-fifth of half-tenths ($\frac{1}{25}\times 0.05$) or two-thousandths (0.002).

Sec. 2. The Theory.

A. Common or statical formula.

§ 12. *Fundamental Relations.*—Suppose A and B, Fig. 1, to represent two stations, and that it is required to determine the vertical distance between them; A and B are not necessarily in the same vertical line. Let C represent any point in A B, and D a point a small distance below C. Suppose the pressure per sq. inch at D to be represented by P, and the difference in pressure between C and D by d P. Let a=the weight of a cubic inch of air under the conditions of presure, temperature, etc., existing between C and D; X=the elevation of A above B, in feet.

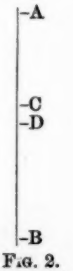


Fig. 2.

It is clear that the increase in pressure from C to D is equal to weight of a column of air between C and D whose cross section is 1 sq. in.; or,

$$a\,dx = d\,\mathrm{P} \qquad (1)$$

§ 13. If a_0=the weight of a cubic inch of dry air at the sea-level in latitude 45° at the freezing point when the barometer stands at 29.92 inches, and P_0=the pressure under which a_0 is determined, then by Boyle and Marriott's law

$$a : a_0 :: \mathrm{P} : \mathrm{P}_0;$$

or
$$a = a_0 \frac{\mathrm{P}}{\mathrm{P}_0} \qquad (2)$$

If H and H_0 represent the heights of the barometer, assuming the temperatures to be the same, corresponding to the pressures P and P_0 and m=the weight of a cubic inch of mercury, then

$$\frac{\mathrm{P}}{\mathrm{P}_0} = \frac{\mathrm{H}m}{\mathrm{H}m_0} = \frac{\mathrm{H}m}{29.92m} \qquad (3)$$

and
$$a = a_0 \frac{\mathrm{H}}{\mathrm{H}_0} = \frac{a_0 \mathrm{H}m}{29.92m} \qquad (4)$$

The weight of a cubic inch of air for any other temperature t is

$$a = \frac{a_0}{m_0} \frac{\mathrm{H}m}{29.92} \frac{1}{(1+ct)} \qquad (5)$$

in which c is the coefficient of expansion of air. For any latitude φ, (5) becomes

$$a = \frac{a_0 \mathrm{H}m}{29.92m} \frac{1}{(1+ct)} \frac{1}{(1+0.0026\ cos\ 2\varphi)}$$

very nearly. (6)

§ 14. Substituting the value of a from (6) in (1), and $m d\mathrm{H}$ for $d\,\mathrm{P}$, we have

$$dx = 29.92 \frac{m_0}{a_0}(1+ct)(1+0.00260\cos 2\varphi)\frac{d\mathrm{H}}{\mathrm{H}}$$

which integrated between the limits H′ and H_1, the heights of the barometer at A and B respectively gives

$$X=29.92\frac{m}{a_0}(1+ct)(1+.00260\cos.\ 2\varphi)\ N\log.\frac{H'}{H_1} \quad (7)$$

Assuming the mean of the temperature of the air at A and B to be the mean temperature of the air between A and B, we may put

$$t=\frac{T'+T_1}{2}, \qquad T' \text{ and } T_1$$

being the temperatures of the air at A and B. Making this substitution and passing to common logarithms,

$$X=5.74\frac{m}{a_0}\log.\frac{H_1}{H}\left(1+c\frac{T'T_1}{2}\right)(1+0.0026.2\cos.\ \varphi) \quad (8)$$

This formula includes the principal relations involved in determining difference of height with the barometer. The final formula to be used in practice has been given differently by different investigators, according to the values chosen for the constants, to the individual preference for one form over another, and to the degree of refinement desired. A few of these special formulæ will now be considered briefly.

§ 15. *The Constants.*—The value of the term $5.74\ldots\frac{m}{a_0}$, generally known as the barometric coefficient, will depend upon whose values of the densities of air and mercury are used. Boit and Arago found* $\frac{m_0}{a}=1046.7$, which makes the barometer coefficient 60,096 3 ft. (18,317 meters). Regnault's values* which are the most recent and probably the most accurate, give 60.384 feet (18,404.8 meters). Raymond (1803 found* the value of the barometric coefficient by determining the value it should have to make the results by the formula agree with those furnished by trigonometrical leveling; the value obtained in this way is 60,158.6 ft. (18,336 meters). Even under the most favorable circumstances, the observations, eight in all†, were too few to determine such a coefficient with sufficient accuracy; for reasons which will appear in this and Chapter IV., it is highly probable that Raymond's coefficient is the least accurate, although it has been more frequently used than either of the others.

The term $\left(1+c\frac{T'+T_1}{2}\right)$ is known as the temperature term. c is the coefficient of expansion of air, and is equal to 0.00375 per $1°c$; it is usually approximated at 0.004. If this value be substituted, the temperature term becomes $\left(1+\frac{2\,(T'+T)_1}{1000}\right)$ for centigrade degrees; if T_1 and T' are given in Fahr. degrees, it is easily seen that the temperature term becomes $1+\frac{T_1+T'-64}{900}$

The term $(1+0.00260\cos.\ 2\varphi)$ is known as the latitude term. A few formulæ still contain an older and less accurate coefficient of cos. 2φ than the above.*

§ 16. *Laplace's Formula.* — Laplace was the first to give a rational formula for determining heights by the barometer, and his formula has served as a basis for several others. It differs from equation (8) as above in having a correction for the variation of gravity in the vertical. If the altitude of the lower station about the sea-level be represented by z, then the weight a at the sea-level as given by (6) must be multiplied by $\frac{R^2}{(R+z+x)^2}$ to make it true for any altitude. This leads to an equation which can be integrated approximately by developing the above factor into a series. All the approximations leading to Laplace's form are not easy to discover, and the importance of the matter does not warrant a long search. Laplace's complete formula is†

$$X=60158.6\log.\frac{H_1}{H'}\left\{\begin{array}{l}\left(1+\frac{T'+T_1-64}{900}\right)\\(1+0.0026\cos.\ 2\varphi)\\\left(1+\frac{X+52252}{20886860}+\frac{z}{10443430}\right)\end{array}\right. \quad (9)$$

In which X is in feet and the temperatures in Fahr. degrees; X in the last term is the value of the preceding part of the formula.

Since the entire correction for the

* Smith, Miscel Col., Vol. I., Pt. IV., p. 9.
† U. S. C. & G. R., 1881, p. 235.

* U. S. C. & G. R., 881, page 227, eq (6).
† Williamson, p. 164; Guyot's Col., etc.

variation of gravity is always quite small, and since at best the barometer can be read only to thousandths of an inch, which corresponds to about 10 ft. of altitude, the latitude term and also the term for variation of gravity with the altitude may be neglected without materially affecting the accuracy of the results. Farther on it will be shown that the appearance of extreme accuracy by retaining these terms can be regarded only as a mathematical illusion, inapplicable to any real state of practice.

§ 17. *Babinet's Formulæ.*—The following formula* by Babinet has no term for the variation of gravity. It is sometimes claimed† that the barometric coefficient was adjusted to meet this correction; from the nature of the case this cannot be true, except for some assumed mean. However, notice that the coefficient is larger than any previously given, see §15. The formula is, for X in feet, and Fahrenheit degrees,

$$\text{Xft.} = 60334 \log.\frac{H_1}{H'}\left\{1+\frac{(T'+T_1-64)}{900}\right\} \qquad (10)$$

If H′ and H_1 do not greatly differ it can readily be found that

$$N \log.\frac{H_1}{H'} = 2\frac{H_1-H'}{H_1+H'}$$

Making this substitution in (10) gives Babinet's approximate formula

$$\text{Xft.} = 52{,}400\,\frac{H_1-H'}{H'+H'}\left\{1+\frac{(T'+T_1-64)}{900}\right\} \qquad (11)$$

"The error involved in the above formula is inappreciable for elevations less than 3,000 feet." ‡

The following§ is essentially the same as Babinet's approximate formula except the value of the barometric coefficient and the form of the temperature term

$$X = 54500 + \frac{T_1+T'-110}{900} \mp \frac{X}{200} \pm 10 \text{ ft.} \qquad (12)$$

The last two terms show the degree of reliance to be placed upon the result.

§ 18. *Correction for Temperature of Barometer.*—In all that has preceded, it has been assumed that the two barometers were at the same temperature, which assumption will rarely or never be true. Therefore the heights of the barometer, before being inserted in the preceding formulæ, must be reduced to the corresponding heights which they would have at a common temperature, or a term must be included in the formulæ themselves to correct for the difference in temperature of the barometers. Both methods are employed.

The expansion of mercury for 1°F. is 0.000,1000, and that of brass, of which the scales are generally made, is 0.0000,104; the difference, the relative expansion of mercury is .000,896. For the centigrade scale this difference is 0.00016141. Hence if h' represents the height of the barometer at the upper station, reduced to the temperature of the lower, and t', t_1 the temperature of the barometers at the upper and lower stations respectively, we have

$$h' = H'[1-d(t'-t_1)], \qquad (13)$$

in which d stands for one of the above differences, according to the kind of thermometer used.

§ 19. Instead of reducing one barometer to the temperature of the other, both may be reduced to any other temperature assumed as a standard; the freezing point of water is generally chosen. Equation (13) is still applicable, provided t_1 be considered as representing the temperature of melting ice (32°F. or 0°C), and t' the reading of the attached thermometer. The formula for reduction must now be applied to both readings of the barometer. Numerous tables have been computed for facilitating this reduction; see Guyot's Collection, 3d Edition, Group C., pp. 61–127; Group D., pp. 30, 46. 53, etc.; Lee's Tables, 3d Ed., pp. 152–9; Williamson on the Use of the Barometer, pp. 1–64 of the appendix, etc.

§ 20. The correction for the difference in temperature of the barometers may be made by inserting a term in the general formula. Thus, in (8), it is only necessary to multiply H′ by $[1-d(t'-t_1)]$ to reduce H′ to the corresponding height at the temperature of the lower barometer. Making this correction, using Babinet's barometric coefficient (§ 17) and

* Smithsonian Miscel. Col., Vol. I, Part IV. (Guyot's Collection), page 68.
† Ibid page 9.
‡ Ibid, p. 68.
§ U. S. C. & G. R., 1876, p p. 352-3; see also Lee's Table, p. 151 (3d ed).

approximating d (.000,896) at .0001, we get *Bailey's Formula.**

$$\text{Xft.} = 60346 \log. \frac{H_1}{H'} \left\{ \frac{1}{1-.0001\,(t'-t_1)} \right\} \left\{ \begin{array}{l} 1+\dfrac{T'+T_1-64}{900} \\ 1\times 0.0026 \cos. 2\varphi \end{array} \right. \quad (14)$$

§ 21. *Correction for Humidity.*—In deducing the preceding formulæ, it was assumed that the atmosphere was composed exclusively of dry air; really it is a mixture of air (oxygen and nitrogen), carbonic acid, and watery vapor. The carbonic acid is very small and nearly constant, and hence it need not be considered here; but the watery vapor is both large and variable. If dry air and aqueous vapor had even nearly the same density under the same conditions, the presence of the latter would not affect the problem; but watery vapor is only five-eighths as dense as dry air, and the weight, a, of a unit of volume of the atmosphere will depend upon the relative amount of vapor which it contains. Accurate hypsometry accordingly demands that some account shall be taken of the aqueous contents of the atmosphere, and a humidity term has been included in many barometric formulæ.

The introduction of a humidity term in the barometric formula requires that the hygrometric state of the air column shall be known. Accordingly an observation with the hygrometer is made at each station. For this purpose the wet bulb hygrometer or psychrometer is generally preferred, because of its greater accuracy and convenience; knowing the readings of the wet and dry bulb thermometers, the barometric pressure due to the aqueous vapor in the air may be determined from tables,† which are the results of experiments. The observed heights of the barometer may be corrected for the pressure of the aqueous vapor before substituting them in the formula; or the observed heights may be used uncorrected, and the resulting altitude be multiplied by a factor to correct for the humidity. The latter method seems to be generally preferred.

"In a very general sense, in temperate climates near the sea level the amount of vapor in the atmosphere is from 0.2 to 0.4 of an inch, or about one-hundredth of the whole."

§ 22. Bessel was the first to propose the introduction of a correction for the effect of moisture. Plantamour's formula,* which differs from the one proposed by Bessel only in the form and the value of the constants adopted, and Rhulmann's formula† are frequently used and are representative of this class. Williamson‡ has translated Plantamour's formula into Laplace's form [9].

§ 23. It is doubtful whether any considerable increase of accuracy is obtained by including a separate correction for the aqueous vapor.§ The laws of the distribution and transmission of moisture through the atmosphere are too little known, and its amount, especially in mountain regions, is too variable and depends too much upon local winds and local condensation, to allow a reasonable hope of obtaining the mean humidity of the layer of air between the two stations by means of hygrometrical observations taken at each of them. The difficulty lies in getting the mean humidity of the vertical column between the two stations. The observations for humidity are made in the stratum of air next to the surface of the earth, which probably contains the greatest amount of moisture, and which is therefore least representative of the vertical column between the two stations. At any rate, the gain, if there is any, is not sufficient to compensate for the extra trouble in making the observations and the undesirable complication of the formula.

The question of the desirability of applying a correction for the hygrometric state of the atmosphere is so intimately connected with the phase discussed in division B of this section, which immediately follows, that nothing farther need be said here.

§ 24. *Conclusion.*—The preceding do not comprise all the formulæ which have been proposed for barometric leveling, but include the more common ones, and illustrate all the principles involved, except those discussed in division B. Some

* Guyot's Collection, D, p. 69.
† Williamson on the Barometer, Table C, of the Appen.; Guyot's Col., Group B., pp. 46-72, pp. 102-6.

* Guyot's Coll., D., p. 72
† 3 U. S. C. S. R., 1876, p 350
‡ On the Barometer, pp. 100-6 of the appendix.
§ Guyot's Collection, D., p. 33.

of the omitted formulæ are approximate, some have empirically determined pressure coefficients, etc. Owing to the limitations discussed in the next division, "it matters comparatively little which of the generally recognized barometric formulæ is used."

B. Dynamical Formulæ.

§ 25. *Defects of Statical Formulæ.*—All the formulæ referred to above are dependent upon the assumption that the air is in a state of statical equilibrium. If a condition of statical equilibrium were possible, we might suppose that the whole atmosphere was arranged in a system of horizontal layers, each of which would be denser than the one above it and rarer than than the one below, each being uniform throughout in temperature and humidity. The temperature and humidity might vary from stratum to stratum uniformly, or according to some more complicated law.

The fundamental assumption in deducing the preceding class of formulæ is, 1, that a difference of pressure is due only to a difference of elevation; 2, that the temperature of the air varies uniformly from one station to the other; and 3, that the temperature of the air between the two stations is the same as that of the vertical column between the horizontal planes of the two points. The introduction of a correction for humidity involves essentially the same assumptions as the temperature term.

§ 26. The air is never in a state of statical equilibrium, but is perpetually undergoing local changes of pressure, temperature and humidity. "For example, the sun, which is the ultimate source of all disturbances, shines only by day. While it shines a certain amount of heat is imparted to the whole atmosphere, but a much higher temperature is given to the ground, and is communicated to the contiguous layer of air. At night the atmosphere loses heat by radiation to space, but the ground loses it still more rapidly and imparts its low temperature to the lowest stratum of air. The lower strata, therefore, have exceptional warmth by day and exceptional coolness by night. If the air is moist it intercepts a greater quantity of solar heat than if it is dry, so that a less quantity reaches the ground, while at night atmospheric moisture checks radiation from the ground. The power of the earth's surface to receive or store or part with heat varies with its character. Naked rocks and cultivated fields, bare earth and grass, forest and snow are affected very differently by the heat rays of the sun, and exert equally diverse influences on the adjacent air, so that one tract of land is often in a condition to heat the air while an adjacent tract is cooling it. Then, too, the sun's heat is unequally distributed through the year; outside the tropics there is a progressive accumulation of heat through summer and a progressive loss through winter. The ocean undergoes less change of temperature than the land, and its rate of change is slower, so that there is frequent, and indeed almost continuous, contrast of condition between it and the contiguous land. As a result of all these influences, together with others that might be enumerated, the equilibrium of the air is constantly overthrown, and the winds, which tend to readjust it, are set in motion.

The temperature of the air is continually modified by external influences; the static order of densities is broken and currents are set in motion; and the circulation and the inequalities of temperature conspire to produce inequalities of moisture. Every element of equilibrium is thus set aside, and the air is rendered heterogeneous in density, temperature and composition."*

§ 27. A consideration of these facts will show the inaccuracy and insufficiency of hypsometric formulæ founded upon an assumed state of static equilibrium. Some of the defects of statical formulæ will be considered in detail before discussing formulæ which seek to overcome these difficulties.

§ 28. *Gradient.*—Let A, B and C designate three barometer stations. Let A′, B′ C′ designate points vertically above each at which the pressure is the same or common. The plane passing through A′ B′ C′ is then a surface of equal pressure; if the air were in a state of equilibrium, it would be a level plane, but in fact it will be inclined in some direction. This inclination is called the *barometric gradient.*

Instead of considering only three

* G. K. Gilbert, in U. S. Geological Report for 1880-1.

points, "we can in imagination project through the air a surface containing all points which have the same pressure; if the atmosphere were at rest, this surface would be a horizontal plane, but under the actual conditions it is never a plane and is ever undulating." For small areas under ordinary conditions, this surface would probably not differ much from a plane.

Conceive another surface passed through all points at which the pressure differs from the preceding one by any constant quantity. With atmospheric equilibrium all such surfaces would be both level and parallel, but in the actual case none are level and no two are precisely parallel. When widely separated surfaces are compared, the variations from parallelism are often so great that their inclinations above the same locality have opposite directions. The atmospheric gradient at the surface of the ground may therefore differ greatly in amount and direction from the simultaneous gradient at a considerable altitude above the same spot.

§ 29. The necessity of considering the barometer gradient is apparent when it is remembered that the air is continually in a state of motion, as is shown in the variation of the height of the barometer. For example, if A and B are two stations, and the atmosphere at rest, then the surface of equal pressure, BC, is a horizontal plane; and AC is the difference of elevation which would be obtained by applying any one of the preceding barometric formulæ. If the air is not in static equilibrium, the pressure at A will be greater or less than before, and the surface of equal pressure may lie above or below BC; if the pressure at A is greater than the average, the surface of equal pressure is above C, say at E, and AE is the corresponding difference of elevation obtained by applying a statical formulæ.

The problem is farther complicated by the fact that the air above B also is in a state of oscillation. If the variations in pressure at the two stations were simultaneous and alike in amount, no error would be produced by the barometer gradient; but these conditions are seldom or never realized.

§ 30. The variations in atmospheric pressure, and the consequent variations of gradient, are so complicated that it is impossible to trace the relation between cause and effect; but there are two variations that are pretty well understood. One has a daily period, and is caused by the variation in the heating effect of the sun between day and night; the second has a yearly period, and is caused by the variations of the sun's heat at different times of the year.

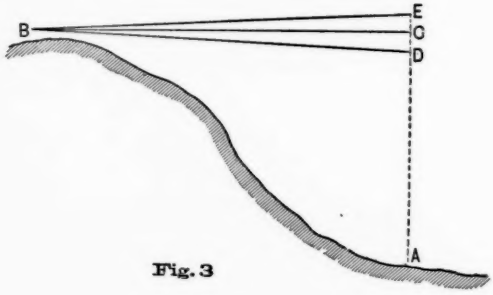


Fig. 3

§ 31. *Diurnal Gradient.*—It is a fact familiar to meteorologists that the pressure of the air everywhere undergoes a daily oscillation. The gradient introduced by this daily change is called diurnal gradient. The pressure has two maxima and two minima which are easily distinguishable. Near the sea-level the barometer attains its maximum about 9 or 10 A. M. In the afternoon there is a minimum about 3 to 5 P. M. It then rises until 10 to midnight, when it falls again until about 4 A. M., and again rises to attain its forenoon maximum; the day fluctuations are the larger.

The daily oscillation is subject to

variations in character and magnitude. The oscillation is greatest at the equator and diminishes toward the poles, but is not the same for all places of the same latitude. Within the United States it varies between 40 and 120 thousandths of an inch. Changes of altitude often cause a marked variation in the amount and character of the diurnal oscillation. The difference which pertains to latitude does not materially affect the ordinary hypsometric problem, but the difference depending on the altitude has a very important effect.

§ 32. *Annual Gradient.*—The annual progress of the sun from tropic to tropic throws a preponderance of heat first on one side of the equator and then on the other, which produces an annual cycle of changes in the pressure and gives rise to what has been called the annual gradients. The amount of this variation is quite small near the equator, but increases rapidly toward the poles; "at the equator it rarely exceeds $\frac{1}{4}$ of an inch per year, while in the polar regions it is often as much as 2 or 3 inches in a few days."*

§ 33. *Non-periodic Gradients.*—In addition to the diurnal and annual variations in the pressure, there are others due to the same general cause, the heat of the sun, but so modified by the local conditions—topography, the humidity, winds, storms, etc.—as to make it impossible to discover the law of their action. These non-periodic variations are much greater in amount and more rapid in their actions than either of the others.

§ 34. *Temperature of Air.*—"It has just been explained that the variations of pressure are due primarily to inequalities of temperature; it will now be shown that, if differences of elevations are determined by the formulæ commonly used, the temperature is directly responsible for other and generally more serious errors." They arise from the difficulty of determining the temperature of the vertical column of air between the two stations.

Let A and B (Fig. 4) be two stations the difference of elevation of which is to be obtained from observations of the barometer and thermometer made at each. Let it be assumed that the pressure observed at B is the same as

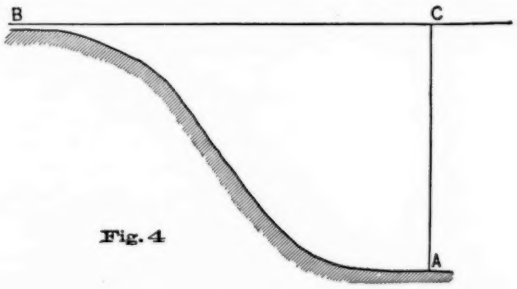


Fig. 4

that at C vertically over A and on a level with B. To use the statical or common formulæ, the temperature of the column AC must be known; in applying these formulæ it is assumed that the mean temperature of this column is equal to the mean of the temperatures observed at A and B.

"How admissible this assumption is will appear at once when the manner in which the air acquires and loses heat is recalled. The body of the atmosphere is heated directly by the sun and gives off its heat by radiation into space. The surface of the earth is heated and cooled in the same manner, but many times more rapidly, so that by day it is always much warmer than the body of the air, and by night it is much cooler. A layer of air next to the earth receives its warmth from the earth, and is thereby caused to differ widely in temperature from the remainder of the atmosphere. Not only is the greater part of the column inaccessible to us, but that portion

* Williamson, page 68.

to which our observations are restricted is the portion least representative of all."*

By measuring the difference of elevation of two points with the spirit level, reversing the barometer formula, and computing the temperature of the air column, it has been found that in middle latitudes the average daily range of the temperature of the body of the air is about 4° of the superficial layer is from 10° to 20° near the sea-shore, and from 20° to 35° in the interior of continents. There is a stratum of air near the surface (Fig. 3) which oscillates daily through this wide range, while the temperature of the upper and larger portion of the column AC is relatively constant. Therefore the mean of the observed temperatures absolutely fails to give the mean temperature of the column AC as required by the formula.

§ 35. Nor does the trouble end here. "Whenever the ground layer is cooler than the air above, it is of course heavier, and, like any other heavy fluid, it flows down hill and accumulates in valleys, forming lakes of cold air. The nightly layer of abnormally cool air is therefore thinner on eminences than in valleys, and the contrast increases as the night advances. When the conditions are reversed so that the ground layer is warmer than the air above it, it has a tendency to rise, but accomplishes the change in an irregular manner, breaking through the immediately superior layer here and there and rising in streams which spread out in sheets wherever the conditions of equilibrium are reached." Observers in balloons, as they ascend or descend, rarely find an orderly succession of temperatures. If, therefore, we could in some way determine the temperature of some point in the upper portion of the column AC, we should still be unable to deduce the mean temperature of the column with a high degree of accuracy."

§ 36. *Humidity*.—The errors in barometric leveling due to the moisture in the air are essentially the same in kind as those due to the uncertainty of the temperature. The observations are made in the stratum next to the earth in which the amount of moisture is the greatest and the most variable. A change of station of a few feet, or a slight variation in the direction or force of the wind, will often cause a very important difference in the amount of watery vapor. The variations in moisture of the different portions of the atmosphere are greater than the variations in temperature. The diffusion of aqueous vapor is so slow that its effect may be neglected, and the distribution considered as taking place only by the circulation of the air. For this reason, then, there will be the same heterogeneity of moisture as of temperature, which has already been discussed.

"The variations in the hygrometric state are still further increased by the laws of condensation. At the surface of the earth there is an almost continuous passage of moisture from ground to air, only a part of the total exhalation being returned as dew. The daily circulation incited by the heat of the sun carries the moistened air upward and eventually the water is returned to the earth in the form of rain or snow, but the condensation and succeeding precipitation are exceedingly irregular. Whenever, therefore, a current of air moves upward and its temperature is lowered by rarefaction, a point may be reached where the accompanying vapor can no longer exist as such, and is condensed to cloud or even to rain or snow. On the other hand, whenever a current of air moves downward, its capacity for moisture is increased, and it acquires a quasi-absorbent power, so as to take up water from whatever moist surface it touches."

The irregularities of humidity are greater proportionally than the associated irregularities of temperature, but the error in the difference of altitude due to humidity is less than that due to temperature, because humidity is a muc smaller factor of hypsometric problems.

Dynamical Formulas.

§ 37. *Ferrel's Formula*.—Ferrel* has deduced from a consideration of dynamical principles, a barometric formula which distinctly recognizes the defects, as discussed above, of formulæ founded upon a statical condition of the atmosphere, and which indicates a method of

* Gilbert in U. S. G. S. Report.

* U. S. C. S. Report, 1881, pp. 225-68.

remedying them. Although the formula is very carefully and ingeniously worked out, yet it is probably of little use for ordinary hypsometrical work, since it requires observations to be made for a long time over a considerable area, to get the data by which to compute corrections for gradient, temperature, and humidity.

Without the data for making these reductions, this formula is essentially the same and has essentially the same defects as the formulæ depending upon a statical condition of the atmosphere. *

§ 38 *Gilbert's Formula.*—Gilbert † has developed a method for determining heights with the barometer which does not require observations of the temperature and humidity of the air. His method requires simultaneous observations of the barometer at three stations, the vertical distance between two of which is known; from the known difference between two of the stations and the observations at each, the actual density of the air can be found; then the true density can be used to compute the difference of elevation between either of these stations and the third.

The method is most accurate when the three stations are in the same vertical and when the one whose elevation is desired lies between the two, the difference of whose elevations is known; the method is applicable, but is less accurate, when the stations are not in the same vertical, or when the one whose height is sought lies either above or below the other two.

"One of the distinctive characteristics of this method is that it observes density directly, whereas other methods observe temperature and moisture only and deduce density. The only reason which has ever existed for measuring the temperature of the air and the moisture in it has been to ascertain its density. A second distinctive feature is that this method employs in its determination of density a column of air comparable in height with the one to be measured and fairly representative of it, while other methods base their diagnosis of the column to be meas ured on density determinations made close to the ground, where, as a rule, the conditions are not representative." It will be shown presently that this method also has serious defects.

§ 39. The formula for this method is deduced as follows:

Let L, N and U represent the altitudes of the lower, new and upper stations respectively; let l, n and u represent the synchronous barometric readings at these same stations corrected for temperature of the instrument and instrumental errors. Let B=the vertical base line, or the known difference of altitude of the upper and lower stations, B=U−L. Let A=the required difference of altitude N−L, and let a=an approximate value of A.

Since B=U−L,
and A=N−L, B−A=U−N.

For convenience refer all vertical distances to the lower station as an origin.

If for the present we neglect the decrease in temperature and moisture with an increase of the altitude, and assume that the accidental or temporary variations of density due to temperature and humidity are the same in both columns, the following proportion may be made:

$$\left.\begin{matrix}\text{The approximate}\\ \text{height of the}\\ \text{base line}\end{matrix}\right\} : \left\{\begin{matrix}\text{the true height}\\ \text{of the base}\\ \text{line, B,}\end{matrix}\right\} :: \left\{\begin{matrix}\text{the approximate}\\ \text{height of the}\\ \text{new station}\end{matrix}\right\} : \left\{\begin{matrix}\text{the true h'ght}\\ \text{of the new}\\ \text{station, A.}\end{matrix}\right.$$

The approximate height (length) of the base line, as deduced from the readings of the barometer at the two stations is, C (log. l−log. n) in which C is the barometer constant. In the same way the approximate height of the new station above the lower is C (log. l−log. u). Substituting these values, the above proportion becomes,

C (log. l−log. u) : B :: C (log. l−log. n) : A.

or $a = \text{B}\dfrac{\text{log. } l - \text{log. } n}{\text{log. } l - \text{log. } u}$ (15), in which a is written instead of A, owing to the neglect of the variation of temperature and humidity with the altitude.

§ 40. The preceding equation would give the correct result if the atmospheric column were uniform in temperature, and if its aqueous vapor were uniformly distributed; but since this is never the case there must be added a term which

* Wm. Ferrel in U. S. C & G. S R., 1881, p. 243.
† In U. S. Geol. S. Report, 1880-1.

shall take account of the variation of temperature and moisture with the altitude.

It is well known that in a general way the temperature and moisture decrease with the altitude; but the exact law of this variation has not yet been discovered. Therefore, before the correction to be added to equation (15) can be determined, it will be necessary to assume some law for this variation.

"If the air were of uniform density, and the element of temperature were introduced alone, the high temperatures at low altitudes would cause a dilation there, and the low temperatures at high altitudes would cause a contraction, and the resulting distribution of densities would be characterized by an increase from below upward. If the air were of uniform density and the element of vapor distribution were introduced alone, the greater per cent. of aqueous vapor (which is a rarer gas than dry air) in the lower strata, would cause them to be relatively rare, and the resulting distribution of densities would be characterized by an increase from below upwards."* Consequently Gilbert* assumes that the increase in density due to temperature and humidity varies directly as the altitude. This may not be the true law, and whenever a better assumption becomes possible it should be introduced instead of the one here used.

In Sec. 3 tests of the complete formula will be given, which will afford an idea of the admissibility of this assumption.

§ 41. To embody this correction in the formula, let D represent the vertical distance in which the increase of density due to temperature and humidity is equal to the density at the ground; then the increase of density for each unit of vertical space is expressed by $\frac{1}{D}$. The mean density of the volume of air between the upper and lower station, in so far as it depends upon temperature and humidity, occurs at its middle point, which is a distance $\frac{B}{2}$ above the lower station. Likewise the mean density of the column between the lower and the new station is at a point $\frac{A}{2}$ above the lower. The vertical distance between these points is $\frac{B}{2}-\frac{A}{2}$. The decrease of density from the middle point of the column A to the middle point of the column B is $\frac{B-A}{2}\cdot\frac{1}{D}$; that is, the mean density of the column A is $\frac{B-A}{2D}$ greater than that of the column B.

In deducing the first term (15) of the proposed formula, it was assumed that the density as far as it depended upon temperature and humidity was uniform throughout both columns; but we have just shown that the element of the density varies directly as the altitude; consequently a term must be added to (15) to correct for the variation. It has just been shown that the mean density of A is $\frac{B-A}{2D}$ greater than that of B. The mean density of B is the unit or standard density; consequently, to express the density of A in terms of B, the density of A, as assumed in (15), must be diminished by $\frac{B-A}{2D}$ A.

Finally, the neglect of the variation of density with temperature and humidity assume too great a density for column A, and since heights are universally proportional to densities, that which makes the density too great makes the height too small; therefore the height of A as deduced from (15) must be increased by the quantity $\frac{B-A}{2D}$ A.

Adding this term to (15) gives for the height A of the new station,

$$A=B\frac{\log.\ l-\log.\ n}{\log.\ l-\log.\ u}+A\frac{(B-A)}{2D} \qquad (16)$$

Since the last term is always small, a can be substituted for A, thereby making the formula more convenient to compute.

§ 42. If the position of the new station be referred to the upper station instead of the lower, the above formula will remain unchanged, except l and n, and l and u will change places.

The formula is applicable, even though the new station is not intermediate in height between the other two; if the new station is above both the others, the quantity (B—A) then becomes minus,

* U. S. Geological Survey Report, 1881, p. 441.

and the last term is subtracted; if the new station is below both the other two, the numerators of both fractions will be minus, and the result will be the sum of the two terms.*

§ 43. The quantity D can be found only by experiment; to find it, observe the barometer at all three stations, determine A and B by a spirit level and compute D. The experiments should cover a great range of conditions so as to secure a fair mean value. Unfortunately D has not yet been determined from sufficiently varied conditions. The only value known is one determined by Gilbert from observations at only two sets of stations, and one of them was not very satisfactory. In this way it was found that D=245,000 feet.

The internal evidence of the observations from which this value is derived is such that it is probable "its real value will eventually be found to be somewhat smaller than the one provisionally assigned." †

Happily, the last term is always relatively small, and hence any uncertainty in the value of D will have only a small effect upon the final result. The uncertainty in the value of D is the chief defect in this formula. Introducing this value of D, (16) becomes

$$\text{A(in feet)} = \text{B}\frac{\log.l - \log.n}{\log.l - \log.u} + \frac{\text{A(B}-\text{A)}}{490{,}000} \quad (17)$$

$$\text{A(in meters)} = \text{B}\frac{\log.l - \log.n}{\log.l - \log.u} + \frac{\text{A(B}-\text{A)}}{149{,}349} \quad (18)$$

§ 44. *Reduction Tables.*—The use of all the preceding formulæ is very much simplified by tables which facilitate their application. Guyot's collection (Smithsonian Miscellaneous Collection, Vol. 1), contains tables for the application of all the principal statical formulæ. The appendix of Williamson *On the Use of the Barometer* contains a series of tables for La Place's form of Plantamour's formula (§ 22), with Regnault's coefficient. The same tables are also given in Lee's Tables, pp. 148–182. The U. S. Geological Survey Report for 1881 contains the only table necessary in applying Gilbert's formula.

Tables are useful where a great number of observations are to be reduced; but they generally contain an unnecessary number of figures, and hold forth a show of extreme accuracy which the nature of the observations themselves cannot justify.

§ 45. In the succeeding section it will be shown that statical formulæ are generally applied in such a way as to largely eliminate the defects referred to in this section. It is impossible to completely eliminate the errors due to gradient, temperature, etc., and, consequently, difference of elevation cannot be determined with precision by means of the barometer.

Section 3.

THE PRACTICE.

§ 46. *Common Method.*—Results may be obtained by using only one barometer, which is carried from station to station, one or more observations being made a each station; but results obtained in such a manner would be only rude approximations, owing to errors of gradient. The greater the distance between the two points the greater the error. Distant stations are sometimes connected by intermediate ones.

The errors due to gradient are partially eliminated by making simultaneous observations at the two stations. If the phase and the amplitude of the variation were the same at both stations, which probably seldom or never occurs, simultaneous observations would give results independent of this class of errors. Errors due to gradient are still further reduced by making a number of simultaneous observations and using the mean; this eliminates only the variable element and fails to take account of permanent gradient.

It is often recommended that the observations be made at certain hours of the day, at which time it is supposed the diurnal and annual gradients are zero. These times can only be determined from experiment, and will vary with the state of the atmosphere, the season, the locality, the elevation, etc. The U. S. Coast Survey* recommend the following times, subject to the preceding limitations. They were probably deduced for the middle Atlantic coast.

The hours refer to the middle of the

* Gilbert, page 442.
† Gilbert, p. 502.

* Report, 1876, p. 349.

month, other times are to be determined by interpolation:

January			1	P.M.
February	10	A.M. and	4	"
March	8	" "	6	"
April	7 30	" "	7	"
May	7	" "	7	"
June	6.30	" "	9.30	"
July	6.30	" "	9.30	"
August	7	" "	7.30	"
September	8	" "	6	"
October	10	" "	3.30	"
November	10.30	" "	2.30	"
December	at no time.			

§ 47. Observations made by the preceding method must be reduced by some of the statical formulæ. Notice that the preceding methods do not eliminate the error due to the fact that the mean of the observed temperatures does not represent the mean temperature of the air column.

§ 48. *Williamson's Method of Eliminating Gradient Errors.**—This method is specially adapted to reconnoissances and topographical surveys. A centrally located station, called a base station, is chosen, at which the barometer is read at stated hours each day for several days. In the meantime, itinerary observers make observations at the various points, the elevations of which are to be determined, and take pains to have their observations correspond in time with one of the observations at the base station. In the progress of the itinerary survey, a series of observations, similar to those at the base station, are made as frequently as practicable at semi-permanent camps; the object of both series being to ascertain the nature of the diurnal variation of pressure and temperature.

The barometric readings at the base stations, corrected for temperature of the instruments, are plotted upon ruled paper so as to exhibit their curve, and all readings shown by inspection to be influenced by abrupt and violent atmospheric disturbances, such as thunder-storms, are discarded, their places being filled by interpolations. From the corrected observations at the base stations, a correction is deduced, which, being applied to the several barometric readings, reduce them to the daily mean; applying this correction eliminates at least part of the effect of diurnal gradient.

Instead of determining the temperature of the air column from the temperature at the time of observing, the mean temperature of the day is used; this can be quite accurately determined at the base stations, but is only approximately known at the other stations. Notice that the mean of the daily means will not be the mean temperature of the vertical air column.

The difference of altitude can then be computed from the reduced barometric readings and the mean daily temperature, by using any of the statical formulæ; Williamson himself used his translation of Plantamour's formula (§ 22).

§ 49. *Whitney's Method.*—"From observations made in connection with the Geological Survey of California, a series of corrections were deduced for reducing the barometric readings made at different hours of the day, of the different days of the the different months, and for the different altitudes to the daily mean for the year. These corrections can only be used in the neighborhood in which the observations on which they were based were made. Similar tables made for different climates would differ materially from each other." For tables constructed upon this principle for the climates of Germany, Philadelphia and Greenwich respectively, see Guyot's Collection, Group D., 3d Ed., pp. 80-1, 93 and 94.

§ 50. *Plantamour's Method.*—In the hypsometric survey of Switzerland, Plantamour made simultaneous observations of the barometer, thermometer and psychrometer at Geneva, St. Bernard, and at the station, whose height was to be determined. The approximate difference of altitude between the new station and Geneva, and between it and St. Bernard, were computed by Plantamour's formula (§ 22); the difference of elevation between Geneva and St. Bernard was also computed. The computed difference of elevation between Geneva and St. Bernard computed with the actual difference of altitude, as determined by the spirit level, gave a correction to be applied to the computed differences for the new stations. The ingenious details of the computation are too complex to be described here.

* Williamson on the Barometer.

Marshall* and Rühlmann applied methods somewhat similar to the above.

§ 51. *Gilbert's Method.*—This method, which has already incidentally been fully described, is somewhat similar to the above, but differs from them in determining the height of the new station by the sole means of the observed pressures. A comparison between it and the several other methods seems to prove that it is the most accurate. †

§ 52. Unfortunately all methods of eliminating gradients involve considerable time and expense, and even then do not thoroughly accomplish the desired end, all of which shows that when great accuracy is desired the barometer should be dispensed with altogether, and the difference of elevation determined by some other means.

§ 53. *Sources of Error.*—The principal sources of error, as well as the means of eliminating them, have already incidentally been discussed, and need only to be referred to here.

1. *Instrumental Errors*, such as index error, imperfection of the scale, imperfect adjustment for capillarity of the tube, impure mercury, and errors in the attached thermometer.

The first is usually eliminated by an adjustment of the zero of the scale, and with a good instrument the others would be inappreciable.

2. *Errors of Observation*, as inaccuracy of making contact between the ivory point and the mercury, inaccuracy of the reading itself, and the inaccuracy in determining the temperature of the barometer. Gilbert‡ from a comparison of 360 pairs of observations made by the Signal Service and the Geological Survey found the average error of observation to be a trifle less than three-thousandths of an inch. This difference does not involve the personal error between two observers, which, for even expert observers, may be nearly as much more.§

3. *Errors due to Gradient*, diurnal, annual, and abnormal, and those due to temperature and humidity. The errors of this class may have almost any value; the various methods of partially eliminating them have already been discussed.

4. *Errors due to the Effect of the Wind.* The wind may cause either a condensation or rarefaction of the air in the room in which the barometer is, or even in the cistern of the barometer itself. This effect will vary with the velocity of the wind, with the position of the openings with reference to the wind, etc. On Mount Washington, a wind of 50 miles per hour caused the barometer to read .13 of an inch too low. Its effect will vary as the square of the velocity. It may be nearly, if not wholly eliminated by having two apertures, one each on the windward and leeward side of the enclosed space.*

A similar effect of the wind is caused when the instrument is read in the immediate vicinity of any body which obstructs the wind. For example, if the barometer is observed on the windward side of a mountain, the reading will be too high; if on the leeward, too low. The only way to avoid this difficulty is in the selection of the stations; but it is not always possible so to avoid it.

§ 54. *Limits of Precision.*—It is sometimes stated that "the barometer is the most accurate instrument for determining differences of level." It needs only a moment's reflection to see that this cannot be true. The following results, given by Professor Guyot, are frequently quoted as showing the great accuracy of barometric instruments:

Mont Blanc, by barometer, 15,781 feet,
by spirit level, 15,780 feet.
Mount Washington, by barometer, 6,291.7 feet,
by spirit level, 6,293 feet.
In North Carolina, by barometer, 6,701 feet.
by spirit level, 6,711 feet.
In North Carolina, by barometer, 5,248 feet.
by spirit level, 5,246 feet.

These results are to be considered exceptional, and only obtained by numerous repetitions in various states of the atmosphere.

The difference of altitude computed from one or even several days' observations cannot be relied upon as being more than a rough approximation. This has been shown by Williamson, † who has computed the difference of altitude between Geneva and St. Bernard (using the same formula as in the last three examples quoted above) for every day for two years from daily simultaneous obser-

* Wheeler's Geological Survey, Vol. II., p. 522.
† Gilbert's U. S. G. S. R., 1881.
‡ Report U. S Geolog. Survey, 1880-1, p. 542.
§ U. S. C. S. Report, 1870, p. 79.

* Gilbert U. S. Geolog. Survey, 18-0-1, p. 562.
† Williamson on the Barometer, p. 306.

vations. The difference between the result by the barometer and the spirit level, in several cases, was more than 3 per cent. Under less favorable circumstances the errors were even more than twice as great. *

The altitude computed by the monthly mean of daily observation for different months of the same year, and also for the same month of different years, differ as much as 1 per cent. †

§ 55. The following differences between the results by the barometer and the spirit level, do not indicate that high degree of accuracy in barometric hypsometry, even where a long series of observations is used, which was formerly supposed to be attainable by this means. The results by the barometer were obtained by computing the difference of altitude from monthly means of the mean of the daily observations, and taking the mean for the time stated. ‡

Sacramento and Summit,
3 years observations, −24 ft. in 6,989 ft.
Geneva and St. Bernard,
12 years observations, −2.6 met. in 2,070 met.
Portland and Mt. Washington,
6 years observations, +37 ft. in 6,289 ft.
Vera Cruz and City of Mexico,
1 years observations +5 met. in 2,282 met.

§ 56. For an interesting comparison of the absolute, and also the relative, errors of the various methods, see Gilbert's Memoirs, Chapt. III, in U. S. Geological Report, 1880–1.

For additional data concerning the accuracy of barometric leveling, see U. S. C. & G. Survey Report, 1870 p. 88; Do, 1871, p. 154–75; Do, 1876, p. 355–76.

§ 57. Although the barometer cannot be regarded as a hypsometric instrument of great precision, yet with care it can be made to give results with sufficient accuracy for reconnoissance or exploration. For this purpose, it is unexcelled by any other instrument, but this is about the only use of the instrument to the engineering profession.

* See also Gilbert, p 456-9.
† Williamson on Barometer, p. 236.
‡ U. S. C. S., 1881, p. 254.

ELECTRIC RAILWAYS.

From "Industries."

The proposal to use electricity as a source of energy for working railways is very old. With whom it first originated will perhaps never be known, but it is probable that Professor Henry's "electric engine," which was invented in 1833, and especially Jacobi's famous experiment in 1839, which showed to the world that electricity could be used to propel a boat, directed public attention for the first time to the question of electric locomotion. This seems the more likely, as the first patent for an "electric railway" dates from 1840, and was granted by the United States Government to Henry Pinkus, who seems, however, not to have developed his invention. We hear nothing more about electric railways until the year 1845, when Professor Page invented a new electromotor, by the aid of which he actually succeeded, six years later, in working trains between Washington and Bladensburg, over a line of five miles in length. The speed was only 19 miles an hour, and the undertaking was commercially a failure, owing to the great cost of producing the electric current which worked the motor.

For the time being the subject dropped out of sight, and has only been revived during the last few years. This revival is in a great measure due to M. Fontaine's discovery—made at the the International Exhibition in Vienna, in 1873—that, by the aid of two dynamo machines and connecting cables, motive power could be transmitted over a considerable distance. Whether this discovery was purely accidental, or whether it was the legitimate and logical result of scientific investigation, is to this day a moot point; but whatever be its history, the practical effect was that henceforth the transmission of power, not only between two fixed dynamo machines, but also between a fixed dynamo machine and a train in motion, has become possible. The actual development of electric railways has, however, only taken place within the last five or six years, and now there are both in

Europe and in America many lines worked by electricity.

There are two ways in which an electric railway can be worked. We may either utilize the ordinary rolling stock, and replace the steam locomotive by an electric locomotive, or we may provide each passenger coach and each goods wagon with its own small electromotor, so that each vehicle becomes its own locomotive. In the latter case, the power is applied to each axle in the train, and the whole of its weight is utilized in producing adhesion. Of the difficulties connected with the conveyance of current to the train, and of those which at present stand in the way of an economical and certain method of regulating the speed, we shall speak presently. But, supposing that these difficulties can be overcome, it will be admitted that electric traction, especially when carried out on the latter plan, has many advantages over steam traction.

By making every wheel in the train a driver, the acceleration at which the train can start is greatly increased. There would be no difficulty in obtaining a speed of 30 miles an hour within 10 seconds from the moment of starting, and the strain due to inertia would not be greater, nor the sensation to passengers more disagreeable, than is the case now, when trains are stopped quickly by the application of powerful continuous brakes. In all probability strain and sensation would be less, because no jarring, as with a brake, would take place. This is a point of great importance for metropolitan railways, where trains succeed each other every few minutes, and where the time wasted to get up speed at every start is a considerable item in the total time required for the journey. On underground lines, the absence of smoke would also be an enormous advantage, resulting in a large increase of passenger traffic. We may here at once remark that the difficulties connected with the conveyance of electricity to the trains are the greater, the longer the line and the fewer the trains which run over it per day. On a short circular line like the Metropolitan Railway, the amount of traffic is so great, that it would pay to place the engine and dynamo almost at every station, and thus reduce the distance through which the current has to travel before it reaches the train, to a few hundred yards. By providing each coach with power, trains can be made up of as small a number of coaches as convenient, and thus a frequent service of short trains can be substituted for the present service of heavy trains at longer intervals —a decided advantage from the passenger's point of view. Another very important advantage is that of almost perfect safety. The late Professor Fleeming Jenkin, when working out the details of his Telpher Line, devised, with the assistance of Professors Ayrton and Perry, an automatic electrical block system, which is intended to prevent one train from overtaking another. As soon as a train enters on a section which has not yet been cleared by the preceding train, the current is automatically withdrawn from the electromotor of the second train, and thus the latter stops for want of propelling power. The first train, in clearing the section, restores the current to the second train, and thus allows it to proceed. Some such arrangement could, no doubt, be adopted on electric railways intended for passenger traffic, and, if added to the ordinary block system, would render collisions almost impossible. Since electromotors contain no parts having a reciprocating motion, such as the piston and connecting-rod of a steam engine, they can run at any speed without oscillation. There is, consequently, nothing to limit the speed of an electrically-propelled car but the tensile strength of the wheel tire, which, under the action of centrifugal force, might burst if its circumferential speed exceed a certain limit. We may mention here, in parenthesis, what is doubtless known to our engineering readers, viz., that this limiting speed does in no way depend on the diameter of the wheel, but simply on the tensile strength and specific gravity of the metal. For good steel, the safe limiting speed is considerably over 100 miles an hour, and it is therefore by no means impossible that about double the present speed of traveling might be obtained in future on electric railways. Speaking on this point at the Society of Arts in 1883, Professor Forbes said that he hoped to live to see the day when he could travel from London to Edinburgh in 3½ hours.

With these remarks we have not yet

exhausted the list of advantages possessed by electrically-propelled coaches over the usual system of trains drawn by steam locomotives. The permanent way, bridges, and viaducts may be built altogether lighter, steeper gradients and sharper curves may be used, and the wear and tear of the road must necessarily be less with light, smooth running electromotors, than with a 40 ton engine pounding along. Now, it might be asked—How is it that, with all these advantages in favor of electric traction, our railways, and, indeed, those of the whole world, are still worked on the train system by steam locomotives? The answer to this question is, that up to the present no satisfactory solution has been found for the three great difficulties which stand in the way of applying electricity to railway purposes.

These are, first, the difficulty of conveying the electric energy to the train; secondly, the weight and high speed of electromotors as at present constructed; and, thirdly, the want of some contrivance by which the speed and power of electromotors could be varied in a simple and economical way.

REPORT OF THE INTERNATIONAL COMMISSION ON THE SUEZ CANAL.

By A. FLAMANT.

Translated from Annales des Ponts et Chaussées, for Abstracts of the Institution of Civil Engineers.

The Commission was appointed in 1884, to determine what new measures, in respect of works and navigation, should be undertaken to enable the ship-canal to meet fully the exigencies of a traffic exceeding 10,000,000 tons per annum. Its Report was presented in February, 1885, of which document the author furnishes a summary. The Commission considered three methods of increasing the carrying capacity of the canal, namely: (1) widening the existing canal; (2) construction of a second canal; (3) doubling the capacity of the canal by a combination of the first two methods. When the canal was first designed, in 1856, it was supposed that two vessels, being towed, could easily pass where the bottom width was 144 feet, or double the normal width adopted. At the present day, however, when vessels of 50 feet in width propel themselves through the canal, a bottom width of 230 feet has been proposed for the 81 miles from Port Said to the southern end of the Bitter Lakes, where the tidal currents do not exceed 1 knot an hour, and 262 feet for the rest of the distance to Suez, where the currents often exceed two knots, in order that the vessels may pass each other freely. The cost of this widening was estimated at £8,240,000, supposing the depth of the canal remained as at present, 26¼ feet below low-water of ordinary spring tides, but would be increased by £975,200 if the depth was augmented to 29½ feet, unless the proposed width could be reduced 18 feet. The construction of a second canal, within the limits of the company's lands, having, like the existing canal, a bottom width of 72 feet, widened out to 131 feet through the small Bitter Lakes, was estimated at from £8,200,000 to £8,920,000, with an additional cost of £698,800 if made 29½ feet deep. The third plan took into consideration the different velocities of the tidal currents north and south of the Bitter Lakes. Assuming that the greater velocity might lead to collisions between vessels passing on a single enlarged canal, it would be advisable to restrict the enlargement to the northern portion, and to form a second canal between the Bitter Lakes and Suez.

The Commission decided unanimously in favor of the enlargement of the existing canal from the Mediterranean to the Red Sea, for the following reasons. An enlarged section would enable vessels to increase their speed from 5⅓ to 8 knots an hour, and thus to traverse the canal in about twelve hours, which could never be accomplished with two separate canals; and, moreover, there would be only two banks to maintain, instead of four. This increase of speed will greatly facilitate the steering, which, together with the

greater width of canal, will enable vessels to avoid stranding on the banks, an important gain which would not be obtained with two canals. The danger of collisions between passing vessels on a single canal will be obviated by the great increase in width proposed for the canal, and by reducing the speed of the vessels in the act of passing. Moreover, the plan of enlargement will include the easing of the curves on the canal, and will thus remove the impediments which these sharp and narrow bends present to vessels of 360 feet in length, which is quite an ordinary length now, though rare twenty years ago. Lastly, this system will possess the inestimable advantage of enabling each successive portion of enlargement to be at once utilized as an addition to the passing places for vessels.

The Commission exhibited some difference of opinion on the question whether, in order to keep within the lower estimate, the depth should be increased at the expense of the width; but it was eventually agreed that the depth should be increased to twenty-eight feet, with a corresponding decrease in the proposed width of the northern portion to 213 feet, and of the southern portion to 246 feet, measured at a depth of 26¼ feet. The present limit of draught is 24½ feet; but it was considered necessary to provide for a probable increase to a maximum of 27 feet, which a depth of 28 feet would just accomplish, leaving the deepening to 29½ feet for a future time, when the increased number of vessels of large draught may demand it. Whilst adopting the above width for the straight portions of the canal, as sanctioned by the experience of navigation on the Clyde, the Tyne, the South Pass of the Mississippi, and the Sulina mouth of the Danube, with similar widths and more rapid currents, the Commission laid down the widths suitable at curves in proportion to their radii. In the northern portion of the canal the widths, 26¼ feet below low water, were fixed at 246 feet for curves exceeding 8,200 feet in radius, and 262 feet for sharper curves; whilst for the southern portion, the widths at the curves, which all exceed 8,200 feet in radius, were designed to be 262 feet. As the long slopes of the canal banks, where unprotected by vegetation, are seriously damaged by the wash of passing vessels, the formation of a narrow berme on each slope, below the action of the waves, about 6½ feet below the water surface, has been recommended, and also the protection of the slopes from that depth up to 3½ feet above the water by pitching. Owing to the increased speed admissible on the enlarged canal, the normal period of transit will not exceed twelve and a half hours, allowing ample margin for stoppages; so that the journey might be accomplished in a single day, if an early start was effected, so as not to be overtaken by nightfall; whereas at present the average time occupied in passing through the canal is forty hours. The Commission considers that the works should be executed in three different stages, namely: (1) An adequate increase in width, to provide for the passing of vessels at any point of the canal, by stopping one vessel and drawing it to the side, together with an increase in depth to 28 feet, at an estimated cost of £2,449,750; (2) the completion of the enlargement to the full width prescribed, at a cost of £5,190,900; (3) the deepening of the canal throughout to a depth of 29½ feet, at a cost of £618,050, making a total estimated cost of £8,258,700 for the whole of the works. Adding, however, £40,000 for sundry expenses, and deducting £180,100 for sale of plant, the final estimate is £8,118,600.

REPORTS OF ENGINEERING SOCIETIES.

American Society of Civil Engineers.—The last number of the *Transactions* contains address of President Henry, read at the Denver convention; a paper on the strength of columns, with some new formulæ by Thomas H. Johnson; a new formula for compression members by R. Krohn.

ENGINEERING NOTES.

Steel Wire for Bridges.—A paper was read by Dr. Percy, F. R. S, at the annual meeting of the Iron and Steel Institute on "Steel Wire of High Tenacity." The writer said that in the address which he delivered to the Iron and Steel Institute in May, 1885, he mentioned steel wire of high tenacity, or, in other words, of great tensile strength, amounting to not less than 120 tons per square inch of transverse sectional area, and he also then said that he had recently seen it stated that mild steel in the form of rod or bar had been produced of equal tensile strength. But as no authoritative evidence was given of the truth of the statement, he determined to search for trust-

worthy information on the subject, and he had now the pleasure of communicating to the Institute the results which he had obtained. In October last he visited the highly-interesting and extensive plough works of John Fowler & Co., at Leeds. His attention was particularly attracted to their steel-wire ropes, for the excellence of which they had justly acquired a high and world-wide reputation. He inquired concerning the tensile strength of the wire which was used for the purpose, and he was astonished to find that it amounted to 150 tons or more. At his request, Sir Frederick Abel, chemist to the War Department, ascertained its chemical composition, and Colonel Maitland, R. A., superintendent of the gun factories at the Woolwich Arsenal, ascertained its tensile strength. Colonel Maitland, in his report, said the steel wire was hard and extraordinarily tough, and so rigid that even with the aid of pillars it required the exercise of considerable force to bend it. It broke when bent on itself, and the fractured surface was ragged, without showing any appearance of grain. The specific gravity of the wire at 60 deg. Fahr. in its original state—that was before Colonel Maitland began to operate upon it—was 7·8142, and after rupture 7·8082. The same weight of wire was used in both these determinations, but as it amounted to only about eight grammes, Mr. Deering suggested that the difference between the two specific gravities might not be greater than the probable error of experiment. It was, however, a difference in the direction which might have been anticipated. The specific gravity of the wire was increased by annealing from 7·8082 to 7·8402—a difference also in the direction to be expected, though Mr. Deering again suggested that it might be within the limits of possible error. The tensile strength of the wire was determined with great care and thoroughness. It broke under a load of 154 tons. The final elongation in the experiment immediately preceding rupture was, with load, 1·1 inch, and without load 0·75. The composition of the wire was as follows:—

Total.	Per Cent.
Carbon	0 828
Manganese	0·587
Silicon	0·143
Sulphur	0·009
Copper	0 030
Phosphorus	Nil.

The wire was carefully examined for chromium, titanium, and tungsen, but no trace of those metals was detected. The percentage of carbon was greatly in excess of what was present in mild steel. After experiments with thicker wires, it appeared that as the diameter increased the tensile strength of the wire notably decreased. The interesting question, Why was it that steel only when in the form of comparatively fine wire should be capable of acquiring such a high degree of tenacity? remained to be solved. Was it that during the process of wire drawing a more intimate interlocking, so to speak, of its particles might occur, which increased its resistance to the tearing asunder of those particles? That such resistance was enormously augmented was certain, but if it were due to the cause he had suggested another difficulty arose, for how, it might be asked, could a more intimate interlocking of its particles be reconciled with the fact that its specific gravity, so far from being increased, as in that case might be reasonably anticipated, actually decreased, or what was equitable, its volume was augmented?

In the discussion which followed, the speakers could not account for the greater tenacity of fine wire, and, although the President was asked for some further explanation, he admitted that he could give no solution of the problem.

Colonel Maitland said the reason he was asked to make the experiments was because the War Office were making guns lined with wire. The wire used was from 90 to 110 tons breaking strain. It was a quarter of an inch in diameter, and a sixteenth of an inch in thickness. The experiments showed that wire might be used of higher tensile strength, but he did not know that that would be of much advantage in gun-making.

Mr. Bateson was of opinion that larger wires might be made to stand equal strain to that of the smaller wire, supposing that mechanical means were provided for doing it—*Architect.*

In a letter dated Carleste Bay, Babadoes, W. I., March 1, 1886, Commander A. S. Barker, commanding the Enterprise, writes as follows:—"I have the honor to transmit a report of deep sea soundings taken between Montevideo and Barbadoes. Seventy-two casts were taken, and the distance run was 5031 miles. In order to avoid the Challenger's track I steered northward towards Nelson shoal, where the chart shows nineteen feet. We found 2088 fathoms when over the spot, but there may be a shoal in the vicinity nevertheless. From this point I steamed slowly, running from about 200 to 250 miles to the northward of the Challenger's line, taking casts at intervals of about sixty miles, the average depth being about 2000 fathoms. In latitude 31 deg. 22 min. south, longitude 36 deg. 39 min. west, the water shoaled to 1469 fathoms, and the next cast, taken in latitude 31 deg 15 min. south, longitude 35 deg. 42 min west, was only 547 fathoms. From this position casts were taken at intervals of five miles or thereabouts until over the shoalest part of the bank. The least depth found by us was 378 fathoms in latitude 31 deg. 2 min. south, longitude 34 deg. 27 min. west. Of course it is impossible to state how much water there may be on the bank in the neighborhood of our casts. It is very doubtful if we crossed the shoalest part, as it extends for about 150 miles in longitude and how much in latitude is not known. If the vessels on the South Atlantic station were provided with deep sea sounding machines they could determine the extent of this bank with very little trouble. After leaving St. Thomas, W.I., we expended all the remaining shot we had on board taking deep sea soundings. The first cast was taken in latitude 19 deg. 53 min. north, longitude 65 deg 45 min. west, where we found 4529 fathoms—excellent cast. The

position of this cast is about 40 east-north-east of that where Lieutenant Commander Brownson found 4561 fathoms."

BRICK MASONRY IN DESIGN.—The endurance with which brick will withstand frost and fire, and the disintegrating forces of nature, in addition to its resistance to crushing and facility of construction, have constituted a very important reason for its value for building purposes: but its use for recent years had been mainly for plain brick in plain walls, whose monotony permitted no artistic effects, beyond a few geometrical devices of the most primitive features of ornament. Additions of cast iron serve as ornaments only in the phraseology of trade catalogues, and the mixture of stone with brick generally results in flaring contrasts, producing harsh dissonance in the design. The facades of such buildings show that this is brick, this is stone, and this is cast iron, but always fail to impress the beholder with the rich sense of a harmonious design. The use of the finer varieties of clay in terra cotta figures laid among the brick work, furnishes a field of architectural design hardly appreciated. The heavy masses of brick, divided by its regular lines of demarkation, serve as the honest element of utility which is fundametal to every design; while the introduction of the same material in terra cotta ornaments at suitable places, gives the most appropriate elements of beauty in the design, for the same material shows alike its capacity for utility and decoration. The absorption of light by clay, whether burned or merely dried, abates reflection and renders its shape more clearly visible than any substance used in building construction. The clay design of a statue embodies a sense of life, received from the hands of the designer; but the glaring plaster cast tells the secret of the embalming process. The present use of enameled brick and tiles afford a method of introducing chromatic effects into brickwork; but the utmost care and restraint is necessary, lest the effect result in a glaring innovation, rather than an artistic touch tending to relieve a monotony of color.—*London Engineering*.

IRON AND STEEL NOTES.

STEEL VERSUS IRON GIRDERS.—A series of important tests have recently been made on Bessemer steel and iron girders by Messrs. De Bergue & Co., of Manchester. These tests, which have been made under the direction of Messrs. Barningham Brothers, of Manchester, on behalf of the Darlington Steel and Iron Company, have had for their special object the determining of the relative strength of steel and iron for structural purposes, and the general results obtained were, with equal sections, about 40 to 50 per cent. in favor of the steel as compared with the iron girders.

EFFECT OF OVERBLOWING STEEL UPON THE ELIMINATION OF PHOSPHORUS.—A. Tamm describes in the *Jernkontorets Annaler* a somewhat curious experiment made at the Vestanfoers Bessemer Works. A charge of 1,850 kilogrammes of pig-iron was blown until it was reduced to only 400 kilogrammes. The following analyses show the composition of the pig (A), the composition of the steel when the flame became short (B), its constituents an hour later (C), and the final product (D):—

	A. Pig.	B. Flame. short.	C. One hour later.	D. Final Product.
Carbon.....	4·05	0·03	0·025	0·02
Silicon.....	1·125	0·025	0·040	0·014
Phosphorus.. .	0·024	0·029	0.046	0·066
Sulphur		Trace.		
Manganese.....	4·40	0 10	0 03	0 03

This proves that, even if overblowing is carried to an extreme, on an acid bottom, the phosphorus is not at all eliminated. The increase, of course, is due to concentration in a smaller quantity of metal.

POLISHING THE INTERIOR OF METAL TUBES.—Within the last twenty years the pneumatic system of transmitting packages has been brought to a practical success; but the tubes, which form one of the principal parts of the apparatus, are very expensive on account of the absence of expeditious means to produce the necessarily smooth and uniform interior required for this purpose. A machine has been invented and recently patented which presents a number of valuable features, and presents probably a complete solution of the problem of rapidly polishing the interior of long sections of iron or other metal tubing, so that the cost is not increased beyond a proper limit, and especially adapts them for the pneumatic system of transmission, to the exclusion of the expensive brass tubes that have usually been employed for that purpose. The machine, as we find it described, consists essentially of a strong iron bed of a trough shape, and of a length to suit the size and length of the pipes to be smoothed. At one end of the bed is attached mechanism for giving a rotary motion to a long bar which has secured to the outer end one or more cylinders of emery. The pipe is held by means of a sleeve which is carried along the bed-plate on a slide, by means of suitable feed mechanism, at the exact speed desired. The sleeve has a pulley attached to it which is slowly revolved by means of a belt in the opposite direction to that of the bar to which the emery cylinders are attached. In connection with the smoothing mechanism is a hose which is so arranged that its nozzle is carried along with the pipe to furnish water for clearing the bore of cuttings, &c., as the smoothing process proceeds. In operation, the bar, with the emery cylinders, is given a rapid speed, then introduced in the end of the pipe, when, being driven in the opposite direction at a slow speed and the interior being lubricated with water, the smoothing proceeds through the pipe at a fair rate, predetermined by the feed apparatus. When the pipe has reached the limit of its movement, the operator, by means of a lever, shifts the belts so that the movement of the feed is reversed and the sleeve and pipe are moved back to the place from which they started, when the pipe is removed and another placed in position to undergo the same operation. This machine is stated to be so perfectly adapted to the purpose that long pieces of pipe

are perfectly smoothed to a uniform diameter at a very rapid rate. The machine will accomplish its work with an operator of ordinary skill, and will greatly cheapen all kinds of tubing in which a smooth interior is required.—*Iron Age.*

RAILWAY NOTES.

THE EUPHRATES VALLEY RAILWAY.—In the *London Times* recently Sir William Andrew has again made a fresh appeal on behalf of the Euphrates Valley Railway. Now that a Premier is in office who is avowedly a warm admirer of the scheme, we shall doubtless hear more about it before long, more especially as Russia's action at Batoum has revived public interest in Asia Minor. The engineering obstacles to the realization of the project are practically *nil*, and we imagine that the line could be constructed easily for the six millions sterling estimated by Sir William Andrew. All along the real impediments the supporters of the idea have had to encounter have been of a political character. On one occasion its success seemed assured, but at the last moment the late Emperor Napoleon intervened, and for the sake of the French alliance Lord Palmerston sacrificed the railway. Recently French rivalry in Asia Minor has died out, and the only opposition would proceed from Russia, who naturally would not approve of any railway abridging the distance between England and India. On the other hand an altogether new factor has been introduced into the matter by the astonishingly rapid extension of the Russian railway system to within hitting distance of our Indian confines. In the opinion of our ablest strategists, if Russia has a railway to India, England also ought to have a railway to India. Such a line would start from opposite Cyprus, and proceed along the Euphrates to the Persian Gulf—being at both ends under the control of our fleet. From the Persian Gulf it would extend along the Persian littoral to Belloochistan and India. It is sometimes said that in time of war Russia might cut it, but this begs the commercial aspect of the question. In the *Contemporary Review* this month Mr. Charles Marvin points out that if Russia penetrates unopposed to the Persian Gulf she will split the continents of Europe and Asia in halves, and dominate the whole of the land routes between east and west. If the construction of the Euphrates Valley Railway would tend to develop the region and prevent Protectionist Russia achieving this great design, surely a guarantee for the six millions would be well spent, in the interest of English commerce, without touching the military aspect at all.

THE heaviest passenger train traffic in Switzerland in 1884 was on the Bodeli Railway, where it was equal to 225 each way daily, while on another it was only 25½; the heaviest freight traffic was only equal to 103 tons each way daily, while the lightest was only 6 tons. The little Rigi Railway (mountain), earned £2938 per mile from passengers, receiving 21¾c. per passenger per mile. The total earnings of the Rigi were £3223 per mile, while the highest on any ordinary railway were £2399. One ordinary railway collected an average freight rate of 11c. per ton per mile, the Rigi getting 4s 3d. per mile for taking a ton up or down the mountain. The cost of working the Rigi was £2160 per mile, leaving £1063.

A RUSSIAN Commission appointed to test rails and tires found: (1) Tires from soft steel are more brittle, liable to break, than hard steel ones. (2) Tires from soft steel wear much more rapidly than hard ones, and are not to be recommended. (3) Very hard steel is bad in use and requires frequent turning up. (4) The best tires contained more carbon and much less manganese than the less excellent, 0·5 per cent. against 0·37 per cent. for carbon, and 0·37 per cent. against 0·76 for manganese. The proportion of silicon to phosphorus is pretty constant in the best tires. The commission recommended changes in the imperial regulations for rail testing, looking to the retention of the bending and drop tests, the former only within the elastic limit, the latter to be tried both with chilled—reduced to freezing temperature—rails and warm ones, with a reduction of the height of fall and omission of a second drop. Each charge is to be tested for the above by taking one rail out and testing it in three pieces separately. In addition, tensile and chemical tests are to be made periodically during delivery, for which limiting figures are set for strength and amount of injurious element, silicon, manganese and sulphur. For tires the drop test is to be reduced and the tensile test retained.

M. HENRY MATHIEU, chief engineer of the Southern Railway of France, has found that the average yearly consumption of sleepers on 80 per cent. of all the French railways for the five years ending with 1882 had been 92 per kilometer, equal to 148 per mile of line, excluding yards and sidings. Returning to the subject recently, he finds in 1883 the average consumption rose to 170 per mile, and in 1884 144½ per mile, and the average for the two years 159 per mile. The *Railroad Gazette* says:—"French railroads are reported to have 1450 sleepers per kilometer, or 2332 per mile, which puts them 27 in. only from center to center, and the consumption for maintenance indicates an average life of from 13⅜ to 16½ years for sleepers. Most of the railways report the number of sleepers used of each kind of wood, from which it appears that in 1883, 69·7 per cent. of them all were of oak, 15·6 beech, 12·1 pine and fir, and 2.6 chestnut and other woods, but in 1884 the proportions were quite different—60 per cent. oak, 22.1 beech, 15.6 pine and fir, and 2.3 chestnut, &c. Of the total number of sleepers reported used, 24 per cent. were imported in 1883, and 20⅔ per cent in 1884. M. Mathieu says that the life of sleepers is increased one-half on the average by preservative processes; that of all the antiseptics tried in France only creosote and sulphate of copper are still used, and the creosote is generally preferred. An oak sleeper costing 5½f. is preserved at a cost of about a franc. On the Southern Railway, where three-fourths of the sleepers used are of the pine that grows on the landes, the sleepers cost from

36c. to 38c. each, and are preserved with copperas for 14c. and with creosote for 19c. each. The Orleans Railroad uses the same kind of sleepers, preserved with creosote, for about one-sixth of the whole consumption. The Northern Railroad finds that the use of a tarred felt paper between the rail and the sleeper increased the life of the latter about two years."

ORDNANCE AND NAVAL.

THE BRENNAN TORPEDO.—Some further experiments have been made at Sheerness, with the Brennan torpedo, the results being described as exceedingly satisfactory. The experiments were carried on in conjunction with the electric search light at the Garrison Point Fort, and the weapon was steered about the harbor in different directions at the will of the operator in the torpedo room at the fort, and was finally directed at a target moored about a mile up the Medway, the mark being rendered discernible by means of the electric light. The torpedo is kept under control and steered by means of a wire attached to the machinery in the fort. When the experiments at the fort have concluded, it is proposed to test the adaptability of the torpedo for use as part of armament of ships of war.

SUBMARINE MINING EXPERIMENTS.—Extensive submarine mining experiments were carried out near Portsmouth on September 14, with the view of testing the efficiency of the present system of firing mines, the system, owing to the weakness of the detonating charges, having broken down at the recent naval review. Two experiments were made. The first was with observation mines, which consisted of a line of six mines, each containing 500 lb. of gun cotton, so arranged as to blow up an enemy's ship should it have crossed the line. The mines were at the bed of the channel, covered with 10 fathoms of water, and connected by an electric tube in which was inserted at each mine a charge of fulminate of mercury. On a key being pressed, four out of six mines were exploded, and each sent up a huge volume of water 400 feet high. Gunboats were stationed 600 yards off, and after the first violent shock the sensation was as though the boats were bumping heavily on rocks. These mines were laid on a mud bottom, large quantities of which, together with tons of fish, were blown up with the water. The next experiment was with a line of 12 countermines, supposed to be laid over an enemy's mined channel, and these also each weighed 500 lb. and were 180 feet apart. On the key being pressed, 11 out of the 12 mines exploded; but, owing to these being laid on a sandy bottom, the shock was no greater to the gunboats than in the first experiment. Tests were carried out on a point of land eight miles from Portsmouth, where the effect of the shock was not felt.

THE "RESISTANCE" TORPEDO EXPERIMENTS.—Under the direction of the officers of the Vernon Torpedo School a protracted series of torpedo experiments was commenced on September 21 at Portsmouth, and will be continued until the Resistance, armor-clad man-of-war, which serves as the target, is blown up. The trial consisted in discharging 60 lb. of gun cotton at a distance of 10 yards from the ship, which is moored in such hollow water that, should she be sunk, she could be approached at low tide. At the trial the vessel was violently shaken by the concussion, but was not otherwise damaged, although it was clear that a much heavier charge would have done a good deal of mischief. The experiments were continued on September 22, and they constituted the first instance of a live Whitehead torpedo having been exploded against the hull of a ship. Hitherto their destructive effects have been a matter of assumption, and the present experiments are calculated to settle many practical questions connected with torpedo attack and defense which demanded a solution. The Resistance being an obsolete ironclad, several things were required to be executed on board to enable her to represent a modern battle ship attacked under approximate conditions. The bunkers below the armor shelf on the port side were accordingly made to represent the actual coal defense which is now applied for the protection of the boilers and machinery of a ship of war against submarine attack. The bunkers were fitted at Devonport with an iron longitudinal bulkhead, which divided them into two equal compartments. The one contiguous to the skin plating was filled with coal, due precautions being taken against firing by the provision of ventilating tubes. By these means there was a thick protection of coal sandwiched between the inner bunker and the wing passage. The whole port side of the ship was also defended against torpedo attack by Bullivant's service wire nets boomed out to the distance of 30 feet. This was the distance which previous trials had abundantly proved to be safe against the destructive force of a Whitehead torpedo; but the weight of such booms and the necessary working gear render them unhandy, cumbrous and burdensome, and the main object of the experiment was to ascertain whether the length of the booms could not be reduced without danger to the vessel attacked. As the purpose was to accurately ascertain the effect of a palpable hit some sacrifice of practical conditions had necessarily to be made to ensure the hit being delivered precisely where it could inflict the most mischief. In actual warfare, it is presumed that the burst of a Whitehead torpedo would prove fatal to a ship wherever it came in contact with it; and although the projectile occasionally proves erratic from no ascertainable cause, save the proverbial refractoriness of inert matter, an ironclad presents so conspicuous a target that the torpedo would be almost certain to hit it somewhere. At the experiments on September 22, it was imperative and essential that the torpedo should hit her, not anywhere, but directly in a certain spot or compartment about 29 feet in length, and extending from the keel flat to the armor shelf amidships. To ensure accuracy, therefore, the old vessel was chained stem and stern in Portchester Lake, in the remote reaches of Portsmouth Harbor. She was a fixture, and in order that she should not have a chance of escape, the time of high

water was chosen, so as to avoid the deflective influence of currents, and also to prevent the destructive agent itself from being arrested in its course by lack of water and coming to an ignominious end in the mud. The instrument of execution selected for the occasion was the old 16-inch Whitehead torpedo. An obsolete torpedo was chosen because, although it may not pursue quite so straight a course through the water as a modern one, it carries considerably more in its head, its full charge of gun cotton being 91 lb. as compared with the 65 lb. of the modern 14-inch Whitehead. The torpedo was also fitted with a new pistol trigger, which is exceedingly sensitive, and explodes the charge upon traversing the meshes of the netting. The Vesuvius torpedo vessel was at a comparatively remote distance to the westward. The effective range of the improved Whitehead is understood to be 600 yards, but as it was expedient for many reasons to attack the net defenses of the Resistance at close quarters, the Vesuvius got underway, and, when passing her at a distance of 100 yards, discharged the projectile. The path of the torpedo through the water was clearly indicated by the air bubbles which it threw up, and though straight, its progress was undeniably deliberate. The torpedo struck the defenses a little forward of the target, but, though the visual force of the explosion was very great, those who expected to see the destruction of the old Resistance were disappointed. As soon as the fountain of water thrown up had subsided, it was manifest that the netting had served the intended purpose, and that, so far as could be seen, the ironclad had not only survived the attack, but remained uninjured. The nearest boom had been unshipped from its support, but the whole of the others remained intact. The meshes in the immediate vicinity of the burst had been carried away, but the area of positive destruction was so exceedingly limited that a second discharge would have proved just as harmless, unless it happened to have passed through the rent in the defenses inflicted by the first. Of course, the exact amount of dislocation on board can only be known after a careful survey, but so far as could be seen the ship was undamaged. The length of the booms will be gradually diminished until the vessel succumbs to the attack. The only foreign representative present at the trial was the German naval attaché. The torpedo experiments were resumed September 24 and resulted in serious damage to the old ship. So far as the experiments had previously proceeded, the results obtained had been little more than verifications and amplifications of the submarine mining data derived from the operations against the Oberon; but last Friday an important step in advance was made, and it was evident to all that the final stage in the endurance of the ship was near at hand. The former experiment had shown that the progress of a locomotive torpedo could be effectually arrested by the ordinary service protective nets now in use, and that the burst of a full charge of gun cotton at the theoretical distance of 30 feet from the ship's side was perfectly harmless. The attack was advanced to closer quarters, and as the value of the nets had been demonstrated, it was deemed no longer necessary to employ costly Whiteheads in the assault. A fixed charge of gun cotton representing the normal explosive energy of a Whitehead was accordingly slung from the booms at a distance of 20 feet from the skin plating (10 feet nearer than before, and submerged at a depth at which a torpedo would be set, and afterwards electrically exploded from a cutter. The explosion produced the usual detonation and spout of water, but its force expended itself in the air without inflicting any perceptible damage to the old hulk, which still continued to hold its own. A second charge of the same character and weight was afterwards sunk 5 feet nearer the ship, that is, 15 feet from the side, and exploded in a similar way. In this case the differences were manifest and significant. Though the volume of water thrown up was about the same, the detonation was less diffused, and, whereas the previous spout was perfectly clean, the outer ridges of the dome in this instance were discolored with mud, and presented a very vague outline. It was evident that considerable work had been performed and that the energy of the burst, being confined to some extent by the proximity of the ship, had rebounded from the harbor bottom. The Resistance, which was held down by four anchors, did not rock, but the shock on board must have been very severe. It appeared, too, at the time, that the explosion had damaged the vessel, as she seemed soon afterward to give a slight list to port, but, as she is divided into numerous water-tight compartments, even had the charge blown a hole in her, her heeling over would not be great. She was, however, greatly strained and shaken, and, though the booms remained in place, and none of the bottom skin was displaced, it began to leak until eventually the wing passage in wake of the target compartment became filled with water, and several runlets found their way into the bilges. During Friday night the water rose 5 in. an hour, and, although thirty men were engaged at the pumps, and were subsequently increased to close upon 300, they could not keep the water under. The diver, on being sent down to examine her sides and keel, reported that the main injury done was the straining of one of her plates; but it has now been ascertained that one of her Kingston valves was also extremely damaged, and the repairs will necessitate a postponement of the further trials. At five o'clock on Saturday morning, the large crew had the utmost difficulty in keeping the vessel afloat until half past seven, by which time she was towed up the harbor and hastily put into dock. Considerable interest was shown in the operation, and many naval officers awaited the clearing of the dock in order to inspect her hull; but a casual observation revealed little damage, the inrushing water being attributed more to the injury to the Kingston valve than to the straining of plates. When her defects have been made good, the Resistance will be taken back to Portchester Creek, where the experiments will probably culminate in her being blown up.

NORDENFELT VERSUS HOTCHKISS GUNS.—Some important trials have been made

at St. Petersburg with quick firing guns of the Nordenfelt and Hotchkiss systems, the weapons used being the 57-millimeter (2¼ inch) caliber. The results of the trial are stated to have been in favor, in every respect, of the Nordenfelt gun. The Nordenfelt gun fired 30 rounds per minute against 20 rounds with the Hotchkiss gun. The penetrative power of the Nordenfelt projectiles was far in excess of that of those used with the Hotchkiss arm, and in proportion to their respective initial velocity, which was 2,050 feet for the Nordenfelt and 1,800 feet for the Hotchkiss gun. The Nordenfelt gun also excelled its rival with regard to precision. Whilst the Hotchkiss projectile did not hit the target, which was 1,800 meters (slightly over a mile) distant, that from the Nordenfelt gun hit it nine times out of ten. A very interesting experiment was made with the two guns, four targets, placed at 600, 800, 1,000 and 1,200 meters respectively, being fired at. The Nordenfelt gun fired 15 rounds in 30 seconds, changing the target at each round, and made nine hits. Under the same conditions, the Hotchkiss gun fired only 11 rounds in 32 seconds, and hit the target only twice. It will thus be seen that, in quick firing, exact aiming at changing targets between each round is much easier with the horizontal and vertical gearing of the Nordenfelt system than with the lever arrangement of the Hotchkiss gun.

BOOK NOTICES

ALBUM OF CRANE DESIGNS. Published by the Yale & Towne Manufacturing Co., Stamford, Conn.

This, although an advertising pamphlet, is almost a treatise on cranes. The brief preface gives a classification and some general directions regarding selection and use of cranes, and ninety plates fully explain the construction of the many kind built by this company.

PHYSICAL LABORATORY PRACTICE. By A. M. WORTHINGTON, M.A. London: Rivingtons. Price, $1.80.

This little book is full of excellent suggestions for teachers. Although most of the experiments are familiar to American teachers, yet as the descriptions given are for the benefit of the learner, the writer, while dwelling especially upon the choice of methods and pointing out the various sources of error, has given the book a value which would otherwise be wanting.

A small equipment only is needed for such a course in practical physics. The present treatise is called a *first* course, which suggests more to come. We have no doubt a further course will be welcomed by teachers who try the present book.

The typography is good and the illustrations are exceedingly well designed.

SHORT LECTURES TO ELECTRICAL ARTISANS. By J. A. FLEMING, M. A. London: E. & F. N. Spon. Price, $1 50.

This work presents in familiar language enough of the theory of electrical science to supplement the practice of artisans who are already engaged in some branch of electrical work. So special attention is given to the principles underlying modern electrical engineering. The reader is supposed to have some familiarity with the technical terms and with the proper use of common forms of electric and magnetic apparatus.

The whole is given in the form of lectures, of which there are nine. The first deals with Magnets, Lines of Magnetic Force; lecture 2d, with Electric Induction; 3d, Electro-Magnets and Magnetization; 4th, Electro-Magnets and Induction Coils; 5th, Electric and Magnetic Measurements; 6th, Instruments for Measuring Electric Quantities; 7th, Measurement of Electromotive force and Resistance; 8th, Primary and Secondary Batteries; 9th, Electro-Motors.

The book will be serviceable to the class for whom it was written.

ELEMENTS OF GEODESY. By J. HOWARD GORE, B.S., Professor of Mathematics in the Columbian University. New York: John Wiley & Sons. 1886. Price, $2.50.

This is a handsome volume of 280 pages octavo. The subject matter falls into two main divisions—the field work and the office work. The treatment is very disproportionate, the field work receiving only about 75 pages. This is by far the most important part of the subject, and has not as yet been adequately treated by any American writer. To be satisfactory it must be done by one who has had a large and varied experience, as it is altogether outside the province of the mere compiler.

The second part contains a clear presentation of the elementary principles of the reduction of a triangulation. It is full enough for the class room.

On the whole we think that the author in compressing a subject so large as Geodesy into less than 300 pages has attempted an impossible task Besides superficial treatment of most subjects, many omissions must necessarily occur. Nothing, for example, is said on precise leveling, and next to nothing on the measurement of vertical angles.

We must commend the care with which the proof-reading has been done.

THE SEPARATE SYSTEM OF SEWERAGE: ITS THEORY AND CONSTRUCTION. By CADY STALEY, President Case School of Applied Science, Cleveland, O., and GEO. S. PIERSON, C E.

This book has a place in the literature of Sanitary Engineering, if for no other reason, because it gives a full, free and unbiased discussion of the separate system from the practical standpoint. The arguments for the necessity of sewerage systems, and for the advantages of the separate system of house drainage, are well stated and not too strongly put. But the strong point of the book is its eminently practical treatment of the subject. The authors have had considerable experience in designing and constructing systems of sewerage for small cities and large towns, and the results of that experence are here given with clearness and in sufficient detail to make the book an excellent text book for the education of city authorities to the necessities of the case in their respective cities. The idea of the specifications presented is good, and the set is probably a copy of one prepared for actual construction. One might

wish some statement as to the practicability of holding contractors to the strict terms of the specifications, which sometimes seem to be a little more strict than could actually be enforced. But the error, if any, is on the right side. The detailed statements of cost of the separate system as constructed in various cities, and the comparisons with other systems are timely, and of much use in presenting the subject to doubting City Fathers.

The hints on house drainage and plumbing find their proper place in the book. They might well have been more extended, for a system of drainage which is good so far as its public portion is concerned may be entirely spoiled by faulty design or construction in the parts which are private property.

The appearance of the book is all that could be wished—beautiful paper, presswork, type, plates, arrangement. There is but one inconvenience, the plates are not all numbered, and consequently one cannot turn very readily to a plate desired.

MISCELLANEOUS.

Welding by Electricity.—Professor Elihu Thomson, the electrician of the Thomson-Houston Electric Company, of Boston, U. S. A., has invented a process of welding any metal or two dissimilar metals together by means of the electric current, and this forms a new application of electricity which bids fair to be as widespread as any of the present uses of electricity furnished by the dynamo. The process is based on the principle that the electrical resistance at a break is greater than any other portion of a conductor; and its application consists in applying the two pieces of metal together and passing a heavy alternating current through the juncture, and the heating at this point due to the excessive resistance fuses the surfaces to a solid union. The apparatus consists of an iron ring, a portion of which is wrapped by a number of turns of fine wire which is part of a circuit conducting an alternating current, which can be varied by means of resistances. Around another portion of the iron ring are a few turns of a large copper bar, the ends of which are attached to a copper clamp; the secondary current is completed whenever any two pieces of metal are secured between the jaws of this clamp, and the current is so great that the electric energy is converted into heat at the union between the two pieces to be joined. The process is almost instantaneous, and the heat is so localized that it does not affect the portions of the article in the vicinity of the joint. As a test of the process, broken blades of penknives and scissors were joined together without affecting the temper of the steel and showing no indications of the treatment, except a narrow dark line at the point of fracture. At the electrical works of the company it is used to join the ends of wires in winding coils, making a perfect butt weld of the same size and electrical conductivity as other portions of the wire, but its application in all forms of mechanical work is almost limitless; it is not confined to small work, such as joining the ends of wires for electrical purposes or for continuous wire drawing processes, but to such forms of butt welding chains, cask hoops, band saws, wagon tires and similar work. When large pieces of metal are used, the electrical work is supplemented by heating the pieces before electricity is used to accomplish the union.

A New Method of Protecting Iron.—M. A. de Meritens, the well-known electrician, has brought out a new method of protecting iron. The article to be protected is placed in a bath of ordinary or distilled water, at a temperature of from 70° to 80° C. (158° to 176° Fahr.), and an electric current is sent through. The water is decomposed into its elements, oxygen and hydrogen, and the oxygen is deposited on the metal, while the hydrogen appears at the other pole, which may either be the tank in which the operation is conducted or a plate of carbon or metal. The current has only sufficient electromotive force to overcome the resistance of the circuit, and to decompose the water, for if it be stronger than this, the oxygen combines with the iron to produce a pulverulent oxide, which has no adherence. If the conditions are as they should be, it is only a few minutes after the oxygen appears at the metal before the darkening of the surface shows that the gas has united with the iron to form the magnetic oxide, which it is well known will resist the action of the air and protect the metal beneath it. After the action has continued an hour or two, the coating is sufficiently solid to resist the scratch brush, and it will then take a brilliant polish. The depth of penetration is shown by the following fact. A gun barrel was oxidized, and then the magnetic coating was completely removed by emery, until the surface again became white It was again returned to the bath, and immediately on the passage of the current the black color again reappeared. If a piece of thickly rusted iron be placed in the bath, its sesquioxide is rapidly transformed into the magnetic oxide. This outer layer has no adhesion, but beneath it there will be found a coating which is actually a part of the metal itself. In the early experiments with this process M. de Meritens employed pieces of steel only. But when he turned to objects in wrought and cast iron, he found that he no longer was successful, for the coating was not fast and came off with the slightest friction. After many trials with currents of different electromotive force, he reversed the order of affairs, and placed the iron at the negative pole of the apparatus after it had been already applied to the positive pole. Here the oxide was reduced, and hydrogen was accumulated in the pores of the metal. The specimens were then returned to the anode, when it was found that the oxide appeared quite readily and was very solid. But the result was not quite perfect, and it was not until the bath was filled with distilled water in place of that from the public supply that a perfectly satisfactory result was attained. The process, it will be seen, is perfectly simple, and demands but little skill in its execution. Now that dynamo machines have superseded batteries as sources of electricity, all that is required is a tank, a quantity of distilled water, and a little power to drive the machine. By placing a number of baths in series, and increasing and diminishing their number, the electromotive force of the current can be regulated without any arrangements of artificial resistance.

Engd by Geo E Perine N York

D. Van Nostrand